

CLIMATE CHANGE, VULNERABILITY AND ADAPTATION FOR SOUTH WEST WESTERN AUSTRALIA 1970 TO 2006

PHASE ONE OF ACTION 5.5, WESTERN AUSTRALIAN GREENHOUSE STRATEGY



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EXECUTIVE SUMMARY

Climate is known to change over geological periods as a result of natural cycles (the Milankovich Cycles) and events such as volcanic eruptions or continental drift. Since about 1780 human actions have also affected global atmospheric processes and regional climate conditions. This recent 'global climate change' or 'enhanced greenhouse effect' results primarily from the release of certain gases from land and forest clearing, fossil fuel use, industrial processes and agricultural production and practices.

The world's major scientific organisations now agree the planet is warming due to increased greenhouse gases, particularly carbon dioxide in the atmosphere, which is causing altered temperature and rainfall patterns, and sea level rise. Scientists worldwide have gathered evidence of these changes, including higher global average temperatures, altered precipitation patterns, lower polar sea ice and mountain glaciers, changed dates of flowering, bird arrival or departure, and changed plant and animal geographic ranges.

Changes to the climate of South West Western Australia (SWWA), which have already been observed have been at least partially attributed to global climate change (IOCI, 2003). These changes can be summarised as:

- 0.8°C increase in temperature since 1910; and
- a 10 to 15 per cent drop in annual rainfall from the 1970s to the present.

The most noticeable impact has affected the region's hydrological cycles, which in turn affects water supplies, public health, biodiversity, amenity value, and the region's industries. The Commonwealth Scientific and Industrial Research Organisation (CSIRO) projects that further drying and warming in SWWA are likely to result from ongoing global climate change.

To prepare for future climate changes, communities, industries and governments throughout the world are beginning to assess:

- how their region's climate will be impacted by global climate change;
- the extent to which they can cope with changes to their region's climate; and
- what responses might be effective for adapting to climate change impacts.

However, little is known about the responses of SWWA's community to the climate changes it has already experienced. Some knowledge of community, stakeholder and professional knowledge uptake and use would inform planning for effective responses to future climate changes.

This report outlines preliminary findings about the impacts of climate changes that occurred during 1975 to 2005 on the South West's people, its economy and natural ecosystems. The report focuses on vulnerability and adaptation, identifying useful pointers for future work, particularly in relation to how well the community, stakeholders and decision-makers understand climate change as an issue and a threat.

The report highlights a conundrum—while the community almost universally accepts climate change as a global reality, its past impacts and future threats are not widely understood by people in the region. Nevertheless, many significant decisions have already been made by residents and businesses in SWWA during the past 30 years that in retrospect appear to be rational and effective responses to local expressions of global climate change.

This implicit inclusion of climate change impacts in ongoing management and investment decisions is most noticeable in sectors for which climate is an intimate factor, requiring continual consideration and integration in small-scale or localised decisions. For example, farmers plan seasons based on expected rainfall, governments plan emergency responses for extreme weather events and health authorities alert people to disease threats associated with certain climatic conditions. The agricultural sector has gradually adopted new technologies and management practices to cope with drying trends. Almost without realising it, the sector, under the guise of 'climate variability', has been adapting to what is now recognised as a significant long-term climate change as part of its annual crop planning and market response activities. The changes are partially obscured by the time period involved and the natural progression of new entrants to farming, but they are revealed by a detailed retrospective investigation.

This ad-hoc process of incremental adaptation contrasts with explicit climate-response decisions and investments by technical professionals and planners. The water supply sector is an exemplar for this response type in SWWA. The observed 10 to 15 per cent reduction in rainfall has resulted in an estimated 50 per cent reduction in stream-flow, which in turn has had a significant impact on surface and groundwater resources. Analysis of these changes and their implications has resulted in the State investing directly in increased surface water catchments and ground water supplies and alternative water sources including a non-climate dependant source; desalination. These significant investment decisions are direct responses to the State's recognised vulnerability to decreasing water supplies associated with documented changes to climate and development of risk management strategies to cope with projected future climate change impacts. The water supply sector now has a significant and ongoing investment in determining future water shortages, thresholds and appropriate responses associated with projected future climate conditions. Though climate change has been a consideration in Western Australia's water planning since 1985, the latest program was a serious socio-political response to a water shortage crisis caused by a run of severe droughts beginning in 2000 that led to the State Water Strategy (2002). The prospect of full sprinkler restrictions in the suburbs of Perth was seen as a 'hot-button' issue and a threat to an \$800 million per year landscaping and gardening industry.

Sectors that are less directly or transparently affected by climate changes than the agriculture and water supply sectors, or which are beset by more urgent issues than global climate change projections, are less able to develop and implement the type of response exhibited by the water supply sector. To this point in time these sectors are more likely to have been faced with responding to slow, gradual change rather than a crisis situation. For instance, the biodiversity protection sector faces threats from salinity, feral predators, dieback fungus (*Phytophthora cinnamomi*), land clearing and ecosystem fragmentation, pest invasions, and inappropriate fire regimes. In the face of these daunting threats, the threat from climate change seems less certain and more remote. Moreover, the biodiversity protection responses to climate change must begin with reducing other threats and thereby increasing the resilience of ecological systems.

In addition to adaptation, some sectors have introduced mitigation responses, particularly during the last 10 years. A number of utilities, and industry and resource sector organisations have focused on mitigating greenhouse emissions in response to government and corporate policies at national and international levels, regulatory pressures and pressures from the environmental movement.

While most sectors are yet to explicitly and comprehensively address climate change threats, they are becoming aware of them. Considering past impacts through the preparation of this report created an environment in which planners and decision makers in SWWA have begun thinking about climate risks and potential future responses. Broader consultation with the general community on these future responses will increase awareness of climate change hazards at a level that is relevant to people's 'zone of influence'. The rapidly emerging challenge is how to combine remote scientific knowledge with local contextual knowledge to empower communities and the institutions they rely on to develop effective and integrated responses.

This report of observed climate change and response in SWWA is, like others of its type, a product of local environmental change and local sectoral vulnerability and capacity to adapt. SWWA is a climate-favoured region in a developed nation. To date, responses to climate change in this region have not been constrained by poverty or a lack of scientific capacity, governance or communication. Where public (generally urban) water supplies have decreased, other sources have been identified and resources found to develop them in a basically 'top down' approach; where agricultural conditions have changed farmers have shown a great ability to cope by adopting new varieties and practices and are justifiably proud of their efforts. It is therefore in some ways a report about how a climate change can be successfully managed. How the region might adapt to future and further climate changes will be the focus of the second stage of this study.

INTRODUCTION

Climate change has emerged as the key environmental threat facing the planet, with observed evidence of its impact increasing. It is no longer a question of whether or not the climate is changing but rather how much is it going to change and how abruptly. The body of scientific evidence for global climate change is steadily growing, becoming a common topic of discussion and debate in the mass media, within and between governments, and among industry leaders and the community.

However, we are operating in an environment of considerable uncertainty. What confronts us is certainty there will be climate change, but uncertainty about the nature and extent of many of the changes and their impacts. While a high level of consensus and certainty exists in scientific and government circles, there is general apathy and resignation among the wider community about climate change. Many find it so overwhelming they're unsure of what to do. Others feel when the issue becomes critical, government and industry will be able to deal with it—technology will overcome the impacts. Few people are aware of some of the impacts of climate change throughout the world: species extinctions, habitat destruction and extreme weather events. Compounding this is the fact that the mass media has only relatively recently begun highlighting climate change issues, and past media coverage has often focused on debate between scientists and politicians about the validity of research supporting the enhanced greenhouse effect.

These attitudes pose problems in communicating with the wider community about climate change and fostering an environment in which it is factored into future planning.

To help overcome this, it is useful to first look at assessing past climate change and impacts. This encourages people to think more critically about how they may have already experienced and adapted to higher temperatures and lower rainfall, and in turn to make links between some of their actions and climate change. If there is one thing Australians like to talk about, it's the weather, particularly rainfall. As Tim Flannery observes in *The Weather Makers* (2005, p. 127) "*Australians—even urban ones—are obsessed by rainfall*". It also assists in identifying key issues that need to be assessed in planning for future changes.

SWWA needs such an assessment. It is an area already experiencing climate change and contains vulnerable social, economic and bio-physical systems. For example, industries such as agriculture, forestry and fishing display vulnerability to climate change. Many regional towns rely heavily on these industries, which contribute to local economies, employ significant numbers of people and have important flow-on benefits for other local businesses. Additionally, regional SWWA is renowned for its tourist attractions, many of which rely on the region's unique biodiversity. These secondary industries are also vulnerable to the adverse impacts of climate change.

The region's capital city, Perth, is also vulnerable to climate change impacts. With the city's water supplies at critically low levels, the Government has to invest in a range of alternative water source development projects. A large proportion of the city's population lives along the

coast and estuaries (arms of the sea stretching inland considerable distances), which may become increasingly vulnerable to rising sea levels and more intense storms.

In 2002 the Indian Ocean Climate Initiative (IOCI) concluded that both natural climate variability and the enhanced greenhouse gas effect have contributed to a significant decrease in rainfall throughout SWWA from the mid-1970s to the present and that Western Australia generally has experienced a 0.8°C increase in temperature since 1910. IOCI also believes further rainfall decline and temperature increases are likely as shown in **Table 1** below.

Table 1 The range of projected changes (relative to 2005) for inland areas of SWWA, from nine international models and under a range of emissions scenarios

| Climate variable | 2030 | | 2070 | |
|------------------------------|---------|------------|---------|------------|
| Mean summer temperature | + 0.5°C | to + 2.1°C | + 1.0°C | to + 6.5°C |
| Mean winter temperature | + 0.5°C | to + 2.0°C | + 1.0°C | to + 5.5°C |
| Mean winter rainfall | - 2.0% | to - 20.0% | - 5.0% | to - 60.0% |
| Potential winter evaporation | + 0.0% | to + 10.0% | + 0.0% | to + 30.0% |

Source: Western Australian Greenhouse Strategy Annual Progress Report, 2005.

Consequently, the State Government, with the Department of Climate Change (DCC), is undertaking a study to investigate the impact of these changes and responses to them. This constitutes Action 5.5 of the Western Australian Greenhouse Strategy, which is:

An integrated global climate and assessment strategy for the South West of Western Australia will be prepared through collaborative action by the DCC, State Government entities, local governments, key stakeholders and the community.

The study is divided into two phases. Phase One is primarily concerned with how residents, organisations, institutions, industries and natural systems have responded to the climate changes we now know have taken place. In essence it seeks to reveal:

- when a decrease in rainfall during the 1970s was perceived as climate change rather than just a variation in climate;
- what brought the nature of the decline in rainfall to the attention of stakeholders;
- when stakeholders determined that a response to climate change was required;
- when stakeholders actually made a concrete response; and
- how the response was conceived and implemented, and how effective it has been.

The study was overseen by a cross-sectoral committee of key State Government agencies called the Action 5.5 Sub-committee, which is a sub-committee of the State's Greenhouse Interdepartmental Committee. It comprises representation from the Departments of:

- Agriculture and Food;
- Environment and Conservation;
- Fisheries;
- Health;
- Housing and Works;
- Planning and Infrastructure;
- Local Government and Regional Development;
- Treasury;
- Tourism;
- Sport and Recreation;
- Water;
- Forest Products Commission;
- Water Corporation; and
- Verve Energy

ACTION 5.5

Why is it needed...?

Following European settlement, SWWA was considered to have had reasonably consistent climatic conditions, particularly consistent winter rainfall. In a continent plagued by highly variable weather and a tendency towards drought (now understood to be an effect of the El Nino-Southern Oscillation [ENSO] cycles), this feature distinguished SWWA from other parts of Australia.

During the 1960s and 1970s rainfall patterns in much of SWWA changed. Early winter rainfall declined significantly, resulting in lower runoff to surface water catchments and groundwater systems. The change occurred abruptly, but the variability inherent in all climate systems masked it for many years. Most of SWWA's residents and resource managers had little reason to be observant for a change at a time when the issue of global climate change remained largely unknown outside atmospheric science.

In the 30 years since that abrupt reduction in early winter rainfall, different sectors have responded to varying degrees. For example, the water supply sector has made significant changes to investment plans while some of the agriculture sector's altered cropping practices have been related to the reduced rainfall. Other sectors have made few visible responses.

While decreasing rainfall is the most notable and pronounced impact to have affected SWWA, a suite of other impacts have been observed. As in other parts of the world, global climate change has caused sea levels to rise and temperatures to increase. These changes have perhaps been more subtle and not as immediately felt as the rainfall change, and hence sectors affected by these variables seem less likely to have recognised them as long-term changes and planned for climate change. On the other hand, sectors with more direct needs for water have been far more alert to climate change.

While most sectors are now aware of climate change as a phenomenon affecting their region, few people and organisations in SWWA are able to confidently include its likelihood in their personal, business or community plans, for the following reasons:

- **Future climate uncertainty.** Predictions about future climate for the SWWA remain highly uncertain in detail, even if there is reasonable consensus as to the overall nature of future climate. The best currently available advice states: *"The latest suite of climate change projections show that even with the most optimistic emission scenarios, SWWA is projected to be drier and warmer later this century, with increasing probability of 'dry everywhere' winter patterns and decreasing probability of 'wet west and central' weather patterns"* (Ryan and Hope, 2005, p. 8).
- **Climate impact uncertainty.** Interactions between climate conditions and sectoral processes and issues are not broadly understood. In some cases there is little known about such interactions, in other cases such knowledge is only held by experts.
- **No clear precedents.** There is no example of a region in which the potential impacts of climate change have been credibly investigated and effective responses planned and implemented. This is because few regions have been identified as having already been clearly affected by climate change. In addition, the requisite analytical tools to undertake such an investigation are still being developed and assessed.

This study is being undertaken to address these concerns by first examining the past as a basis for identifying the key issues that need to be dealt with in the future. Looking back provides a mechanism for ensuring that future work is well targeted by:

- defining the critical sectoral and cross-sectoral issues that are likely to emerge in the face of climate change;
- identifying information requirements and critical decision issues that will need to be addressed;
- identifying geographic locations where changes have been experienced;
- ascertaining community, industry and government understanding of the issue; and
- unearthing issues that were not previously considered or may have been overlooked, often based on local knowledge and decisions, which in retrospect appear to be logical responses to local expressions of global climate change.

It also helps to raise awareness of climate change and the need for people to begin thinking about how they are going to adapt in the future.

Phase One is also aimed at generating information essential for a proposed Phase Two of the study. Phase Two will build on the research and social processes of Phase One and is aimed at highlighting SWWA's vulnerability to future climate change and determining responses to address this vulnerability. Fundamental to this will be key decisions on issues such as water allocation, where there is increased demand but decreased availability. These considerations are critical because a barrier to integrating climate change impacts into planning is the uncertainty about its impact on social, economic and environmental systems.

Phase Two proposes to:

- investigate the uncertainties and reduce them where practicable;
- assess methods for analysing and planning within the constraints that uncertain information imposes;
- assess the use of these methods and their products;
- generate a set of response strategies concerned with enhancing the resilience of SWWA to the occurrence of projected climate change; and
- bring the best available science about climate change into the public arena to raise people's awareness and empower them to plan for and respond to it.

Why vulnerability and adaptation...?

Assessing the vulnerability of our institutions, industries, economic systems, and natural and built environments will help determine risks by revealing the extent to which we can 'cope' with climate change. Where systems can no longer cope, or are nearing critical thresholds that challenge their coping capacity, decisions need to be made about appropriate responses.

Risk management is used as a tool to assess the likelihood of certain impacts, improving our understanding about how climate change will affect people, industries, and ecosystems. Risk can be measured using concepts such as coping range, critical thresholds, and through integrating climate risk with other elements of change. This provides an indication of 'vulnerability', or the ability to experience the adverse impacts of climate change. A major factor affecting vulnerability is the availability of mechanisms to manage or adjust to changes, often referred to as adaptive capacity (Preston and Jones, 2005, p. 20).

Phase One suggests SWWA's social, economic and environmental systems have been reasonably robust and resilient to the impacts of climate change. There appear to be no instances identified where climate change has outstripped a sector's coping capacity. Even in the case of the agriculture and water resources sectors where climate change impacts are most pronounced, strategies have been developed to overcome the reduction in rainfall. However, the extent to which various sectors will be able to continue to adapt in the future is uncertain.

For example, if rainfall in the South West continues to decline, eventually dropping below a critical level for growing wheat, what will be the impact on the agricultural industry and how will it respond; and in turn if agriculture is affected, what will be the impact on regional towns where agriculture is the predominant industry? Likewise increasing temperatures may increase the incidence of heat related illnesses, to which the health sector may respond by increasing community awareness and investing in research to alleviate heat stress in vulnerable segments of the population.

A range of responses will be available for sectors to choose from in any given scenario. However, choosing responses will likely present conflicts as it implies a need to prioritise and determine trade-offs. Some adaptation strategies may be infeasible or too costly making the response a 'do nothing' or 'walk away' scenario. On the other hand the costs associated with doing nothing may be outweighed by the need to protect an asset that is highly valued by other sectors of the community. Communities and their policy and decision makers will need to make these choices and will need clear and open prioritisation processes to inform their decision-making. Phase One of the study has assisted in identifying some key climate change decision issues, but considerably more work will be needed in Phase Two to develop and test tools for decision-making.

So why look predominantly at adaptation once we have determined vulnerability? The reason is because it is now widely accepted that even with substantial efforts to reduce greenhouse gas emissions, future climate changes of the type experienced during the last 30 years are inevitable. It is fairly well established that temperatures and sea levels will continue to rise, and for SWWA ongoing decreases in rainfall seem very likely. We can expect to live in a climate that is warmer, has different rainfall patterns, less available soil moisture and more severe storms. As a result the region's people are going to need to learn to adapt (DCC, 2006, p. 11).

Responses based on adaptation are well suited to an environment where uncertainty dominates. Adaptation implies objective setting, ongoing monitoring, review and refinement rather than inflexible adoption of a particular strategy. This will assist in avoiding potentially costly mistakes, where investments could be made in adopting technologies or strategies that are ultimately unsuitable for the particular climate impacts that eventuate.

SWWA is in a good position to develop adaptation strategies due to its stable economy, a comparatively high level of affluence, well developed social and political institutions and a reasonably healthy environment. In this regard the region, as with the entire country, has a responsibility to lead action in adapting to climate change and build knowledge and strategies that may be transferable to other parts of the world.

Assessing vulnerability and adaptation needs to be incorporated into all sectoral decision making, and early consideration will ensure industries and communities are well placed to deal with climate impacts. Particularly given the greenhouse gases already accumulated in the atmosphere will drive climate changes for the next 30 to 50 years, and there is reasonable certainty of the levels of these and the likely impacts (DCC, 2005, p. ix).

The DCC's (2006) *Climate Change Impacts and Risk Management—A Guide for Business and Government* provides a useful tool for assessing sectoral vulnerability to climate change. It outlines a framework and step-by-step process for determining potential risks to climate change, prioritising these risks and developing management actions to address them. This framework will be a key tool for sectoral risk assessments that will take place as part of Phase Two of the study.

Looking at the past—laying the groundwork for future risk assessment

The study is essentially the first step in assessing SWWA's risk to climate change. While Phase Two will make use of the best available science and analytical tools to assess risks and impacts, and in turn develop responses, it is useful to first determine:

- awareness of climate change issues and sectoral interest;
- observations of climate change;
- major sectoral shifts in policy and strategic direction and any possible relationship to climate change;
- currently available information and local knowledge; and
- information needs for future planning.

As pointed out in the DCC's (2005) report on vulnerability and adaptation, issues vary considerably according to people's activities, attitudes, and where they live. The report highlights that planning for climate change, and indeed acceptance of the need to begin planning, is more apparent in some places than in others. As SWWA is identified as a priority for assessment it is useful to first know how widespread is the perceived need for climate change planning. While current literature on climate change and its impacts is reasonably extensive, it needs to be considered in light of 'on-the-ground' understanding of key issues, opportunities and imperatives to form a more complete picture of priorities and risks (DCC, 2005, p. 19).

This is the underlying logic behind Phase One—that is before we launch headlong into assessing the vulnerability of the region and developing detailed and perhaps complex adaptation strategies, let's first understand whether or not people even understand the issues, the processes at work, the actions and aspects of their daily lives that are vulnerable, and their capacity to plan for the future.

Criteria for risk assessment and priority setting

The term 'criteria' is defined as—*a standard, rule, or test on which a judgment or decision can be based* (American Heritage Dictionary, 2000).

There are two aspects to developing criteria for adaptation to climate change.

Firstly there is a need to **assess and prioritise risks** at a sectoral level, where criteria will need to be focused on factors such as impacts over time, extent, severity and the likelihood of impacts occurring.

Through this process sectors can identify the areas in which critical decisions are needed and where thresholds may be reached. For example, as available rainfall is a key decision issue for agriculture and forestry, there will be critical thresholds for deciding when climate impacts will outstrip coping capacity. Sectoral knowledge will need to be tested against future projections for climate change to determine when and where critical decisions will need to be made. Similarly heat related mortality thresholds for humans, particularly the elderly, are well known and these need to be matched against projections for temperature increases and

incidence of heat waves. In another example, the strength of the Leeuwin Current is known to affect distribution and health of the western rock lobster fishery off SWWA's coastline. This is understood sufficiently well that the sector can predict lobster population numbers years in advance, based on its knowledge of the current, and make critical decisions about future numbers and catch. It's also known that the current is influenced by particular climatic events. However, the extent to which these climatic events will in turn be influenced by climate change is not well understood. In this scenario thresholds for decision making have been determined but the precise risks posed by climate change are unknown.

Secondly once the level of risk has been determined, people will require criteria against which they can **prioritise actions and determine trade-offs** in light of improved understanding of their vulnerability and coping capacity.

While risks can be determined on a sectoral level, the process of prioritisation and ultimately decision making needs to be cross-sectoral. This is due to the pervasive nature of climate change impacts and because there is the potential for some responses to create conflicts or synergies between sectors. Prioritisation through this process should involve strategic questioning of proposed actions to encourage consideration of:

- the provision of public benefits (based on value for money spent);
- time criticality;
- the capacity for implementation; and
- the cost-benefits of implementation.

Phase One has gone some way toward highlighting potential responses to climate change, however more work is needed in Phase Two to undertake comprehensive risk assessment and prioritisation of actions for addressing future climate change.

Phase One

Outputs and methodology

Phase One is comprised of three parts. They are:

1. a historical desktop review for the period 1960 to 2000;
2. stakeholder consultation; and
3. a scoping study report.

Part 1: Historical review for the period 1960 to 2000

The Action 5.5 Sub-committee undertook an historical desktop review, assembling the best available information from the range of sectors in SWWA on past experiences and responses to climate change. The review culminated in a report titled *Climate Change and Adaptation in the South West of Western Australia, 1960–2005*, which demonstrates whether sectors have perceived the climate changes demonstrated by the IOCI, and if so, how they have responded and adapted to them.

The report is essentially a technical and expert overview of climate change in SWWA, and has been a key resource for informing this document and for planning Phase Two. It provides an overview of major sectoral changes during the last 30 years and the extent to which some of these have, or may have, been influenced by climate change.

In summary it shows that most sectors are now aware of climate change as an issue and of the need to plan for its future impacts. Several sectors found the exercise difficult as their historical data sets, records and reports were not developed with climate change issues and concerns in mind. Hence it is difficult to link many advances in technology, policy shifts and key strategic directions directly to the impacts of climate change.

While a problematic exercise in some ways, it was useful in highlighting some key areas for consideration regarding climate change. For example:

- the increased risk of extreme events and subsequent implications for local government, housing, and planning agencies;
- the need for increased disaster response planning;
- the impacts of sea level rise on coastal infrastructure and the region's booming coastal housing developments;
- implications from ongoing reductions in rainfall for water supply, and increasing competition for water;
- the increasingly vulnerable nature of agriculture and forestry, particularly at locations experiencing extended periods of drought;
- a lack of knowledge about the direct impacts of climate change on the biodiversity in SWWA, which is one of the world's 25 biodiversity hotspots;
- the health effects of climate change, particularly temperature-related mortality and vector-borne diseases; and
- a need to better understand climate change impacts on sport, recreation, lifestyle and tourism in SWWA.

Part 2: Stakeholder consultation

This part of Phase One sought direct community input on experiences and adaptations to past climate change, and thoughts about the impacts of climate change in the future. It was largely undertaken through a formal consultation period during March 2006. Consultation sessions were undertaken at Katanning, Ravensthorpe, Albany, Perth, Bunbury and Geraldton, and a broad range of people were invited to attend from community, industry and government organisations and sectors. These particular locations were chosen because they are considered to provide good coverage of the range of sectoral issues and interests, and have experienced the impacts of climate change.

The structure of the sessions comprised two parts. First, participants were provided with an overview of previous climate changes and asked to give comments and observations on local conditions and experiences. Secondly, a brief outline of climate change projections was provided and participants were asked to comment on the potential impact of these on their activities and how they believed they would respond. In this second part, participants were also requested to highlight information that would be most useful to them in developing adaptation strategies.

As well as the formal consultation sessions, the study team sought a number of other opportunities to discuss the study and seek feedback from stakeholders. The outcomes of the stakeholder consultation is detailed in a technical bulletin *Community, industry and government views on past and future climate change for South West Western Australia* (2006).

Part 3: Scoping study report

Part three's scoping study report is this document, which is the culmination of information generated through parts one and two, plus additional research and consultation. It is the key source document for informing additional work to be undertaken through Phase Two.

Phase Two

COMBATING



Phase Two will produce packages of information, assess methodologies and tools, analyse the vulnerabilities of SWWA to climate change and make recommendations to enhance the region's resilience, with particular regard to resource allocation or long-term (multi-decade) investment decisions likely to face residents, businesses and governments.

The following summarises Phase Two's broad outputs and methodology, which is essentially a risk management approach based on the best available science to support better decision making and raise public awareness. The outputs were created after consultations during Phase One and are designed to meet sectoral and cross-sectoral needs to assess vulnerability to climate change.

Outputs

It is intended the core outputs of Phase Two will include:

1. **Planning database for SWWA.** This output will comprise a meta-database of the information assembled and used for Phase Two. It will enable decision makers in SWWA to use relevant information when integrating climate change into planning and decision making.
2. **Planning and decision making scenarios.** This output will comprise the best future SWWA climate projections available from Australian climate scientists, expressed in terms, and at temporal and geographic scales, that are relevant to SWWA circumstances. The scenarios will enhance the capacity of policy makers, natural resource management groups and other community groups, government agencies and industries in SWWA to more confidently include climate change in their plans and strategies. In particular the scenarios will be critical for sectoral risk assessment.
3. **Planning and analysis of methods.** This will comprise an assessment of alternative methods of undertaking integrated regional climate change assessment in conditions of uncertainty. The assessment will be focussed on comparison of functionally different methods with a view to informing further integrated assessments of SWWA, and indeed subsequent assessments in other parts of Western Australia and Australia. The methods will also aid sectoral assessments as they will support better understanding of the interactions between sectors. This output will assist decision makers in SWWA and elsewhere to understand the potential use of alternative options for integrated regional analysis of climate impacts.
4. **Integrated, regional vulnerability assessment.** A set of integrated, regional vulnerability assessments will be generated. It will include an assessment of the most useful findings for future planning and investment, considering the potential for both gains and losses. It will provide a basis for prioritisation and decision-making at regional and sub-regional scales and inform decision makers in other parts of Western Australia and Australia about the potential application and outputs of the analytical methods used.

5. **Response strategies.** A set of response strategies to enhance the resilience of SWWA under the projected climate change will be developed. The implications of alternative options for different sectors will be outlined and key issues discussed. The response strategies will provide advice on specific issues of concern for SWWA and provide information to residents of other regions about the way research can be applied to decision-making.
6. **Capacity building.** Knowledge and empowerment resulting from community information produces outputs. This adds to the confidence of decision-makers, who will be able to use the information when considering their personal, community or work decisions, leaving a heritage of informed SWWA community members who will be better able to successfully incorporate climate change in their ongoing decision-making activities.

Methodology

Information collection and management

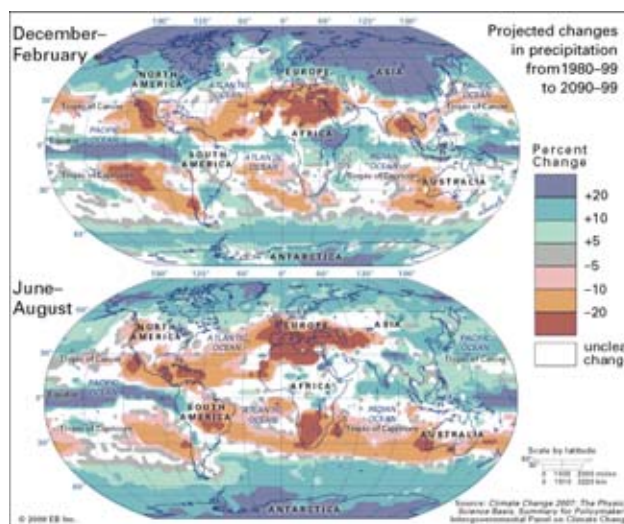
Information collection and management will be achieved by establishing a database, which will be the primary repository and ultimately key resource for detailing outcomes and outputs from Phase Two (and Phase One). As such it is a very important component and its development will receive high priority.

Major outputs and outcomes from Phase Two will be widely available via a website to aid decision makers, planners and the wider community prepare for climate change. The database will support development of this website, which will be a major, 'visible' product of the study.

Climate science

Future scenarios are considered to be a key resource for enabling sectors to strategically plan for climate change impacts, and the resultant cross-sectoral conflicts that may occur. Developing climate change scenarios was highlighted several times as a particularly useful tool throughout Phase One.

Information from Phase One and ongoing interaction and review with stakeholders and climate scientists will drive development of the scenarios to be used in the vulnerability assessment. Scenarios will be developed to test vulnerability under both 'most likely' and 'extreme' situations and over meaningful time frames.



Phase Two will engage scientific expertise in CSIRO and the Bureau of Meteorology to develop the scenarios, through the IOCI partnership. The scenarios will provide information that can be factored into risk and vulnerability assessment, and response planning activities.

Integrated vulnerability assessment

This is the core component of Phase Two, which will require three steps.

1. There will be an analysis of the methods used to carry out a vulnerability assessment. This will include a review of methodologies, determinations of their relevance and usefulness, and a report with recommendations on the most appropriate ways to undertake the analysis. This will give consideration to appropriateness in relation to the various geographic scales of the study.
2. Appropriate methodologies will be applied to the scenarios at the determined geographic scales. Application at different scales will help pick up the diversity of impacts that are likely to occur between sectors and provide information for different levels of decision-making. For example, information generated at a South West region scale will be useful for public policy makers setting priorities and allocating resources, whereas at a local scale it will assist community organisations, industries and local governments in planning for climate change impacts. Given the growing importance of regional natural resource management planning and investment processes in Australia, information generated at a sub-regional level will be particularly pertinent. It will help inform these processes, particularly prioritisation, where decisions need to be made about how climate change impacts 'stack up' against other natural resource management issues such as salinity, native vegetation decline and deteriorating water resources. It will also help in highlighting possible links between these processes and climate change.

The analysis will use action learning principles involving repeated interaction between scientific and community stakeholders. The best available scientific information and assessments will be presented to community, industry and government organisations to determine the likely impacts, potential conflicts and possible adaptation strategies.

Further critical information and assessment activities will also be generated. This will generate better information about each sector's vulnerability, resilience and capacity for adaptation and the critical thresholds beyond which it might no longer cope.

Assessment will focus on threats, vulnerability and impacts to:

- human health and well being;
- biodiversity;
- water resources;
- managed terrestrial systems such as agriculture and forestry;
- industry, energy and resources;
- marine and coastal systems;
- public and private infrastructure; and
- tourism, lifestyle, sport and recreation.

Climate variables likely to be considered include:

- rainfall and seasonal shifts;
- temperature changes including incidence of extreme variations;
- sea level rise; and
- extreme events such as droughts, cyclones and storm surges.

The study will use analytical techniques for decision making under uncertainty, which will be qualitative and quantitative depending on sectoral requirements.

A report will be prepared highlighting SWWA's vulnerability to climate change on a regional, subregional and local basis and for each sector, which effectively provides a comprehensive climate risk assessment for the region. The report will also report on cross-sectoral concerns, impacts and conflict resolution.

3. The final step to complete the vulnerability assessment is to report on adaptation strategies that can be employed by various sectors to cope with climate change. This will highlight trade-offs required as a result of implementation and where mutually beneficial outcomes can be achieved. Cross-sectoral impacts of adaptation strategies will be considered to determine how one sector's adaptation strategies might affect others.

Recommendations for adaptation need to consider the uncertainty associated with climate change and its potential impacts. Consequently, decision-makers will need information about proposed responses to inform the level of adaptation. For example if the impacts of climate change in relation to a particular issue are highly uncertain, then caution may need to be exercised in deciding the level of investment in a particular response to address that issue.

Capacity building

Improving community capacity to deal with climate change impacts was identified during Phase One as a critical need and consequently will be a key focus for Phase Two. It will be a major area of activity for the duration of the study, focusing on communication and effective community involvement. It will be closely linked to the information management component of the study and include:

- ongoing product development and distribution as new information comes to hand;
- ongoing networking and communication with key stakeholders; and
- the identification of capacity building needs and development of strategies to meet these.

FEATURES OF CLIMATE CHANGE

Major global climate changes



The concentration of CO₂ in the Earth's atmosphere is said to have increased by 31 per cent since 1750, with the current rate of increase unprecedented during at least the past 20,000 years. Approximately three quarters of the human-induced

emissions of CO₂ during the past 20 years are a result of burning fossil fuels, with the rest attributable to land use change, particularly deforestation (Pittock, 2003, p. 23). Additionally there have been significant increases in the levels of methane and nitrous oxide, and 65 related gases termed halocarbons, which are also greenhouse gases. Greenhouse gases absorb heat radiated from the Earth's surface, and therefore, higher levels of them lead to higher surface and air temperatures (Pittock, 2003, p. 11). This in turn has other effects such as altered rainfall patterns and increased sea levels.

The global average surface temperature of the Earth has been increasing since 1861, and during the 20th century has increased by about $0.6 \pm 2.0^{\circ}\text{C}$. However, records show a great deal of variability. Most of the warming has occurred during two periods—1910 to 1945 and 1976 to 2000, and it is only in the late 1970s that the temperature started to consistently exceed the 1961 to 1990 average. What is significant about the late 20th century is the *global* nature of the warming, particularly since 1970 (Pittock, 2003, pp. 24-25).

As a result of recent warming, sea levels have risen. New estimates of the rate of historical sea level rise confirm rates reported by the IPCC in 2001; a combination of tide gauge and satellite altimeter data shows a global average sea level rise of 195 mm from 1870 to 2004 (Church and White 2006, cited in Steffen, 2006). From 1950 to 2000, global-averaged sea level rise was 1.8 ± 0.3 mm per year, but during the 1970s, and again since 1993, the rate of sea level rise has increased to about three mm per year (White *et al.* 2005; Church and White, 2006, cited in Steffen, 2006). The contemporary rise contrasts with the last 6000 to 7000 years, during which sea level has been relatively stable or has fallen slightly from higher levels earlier in that period (Harvey and Goodwin, 2004, cited in Steffen, 2006).

The observed sea level rise is due to both thermal expansion of the ocean and the increase of runoff from the melting of glaciers and ice sheets. The contribution of thermal expansion is estimated to be 0.4 mm per year or less from the 1950s to the 1990s (overall rate of sea level rise of 1.8 mm per year), and about 1.8 mm per year after 1993 (overall rate of sea level rise of three mm per year). These figures imply significant contributions to sea level rise from the loss of land-based ice (Church *et al.* 2004; Church and White 2006, cited in Steffen, 2006).

To predict the rate of future climate changes, the IPCC has developed a range of greenhouse gas emissions scenarios documented in the *Special Report on Emissions Scenarios* (SRES). Under the SRES scenarios, globally averaged surface air temperature is projected by models to warm by 1.4 to 5.8°C by 2100 relative to 1990 (IPCC, 2001, p. 3). This suggests a warming trend about twice to ten times that observed during the 20th Century, which was approximately 0.6°C (Pittock, 2003, p. 29).

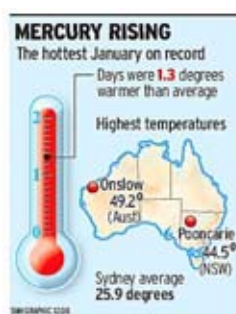
As a result of this warming trend, globally averaged sea level is projected to rise between nine and 88 cm. This indicates that warming will vary considerably between regions and be accompanied by varying increases and decreases in precipitation rates, and consequently surface and groundwater recharge rates (IPCC, 2001, p. 3). A consistent projection from most climate change scenarios is for increases in annual mean streamflow in high latitudes and south-east Asia, and decreases in central Asia, the area around the Mediterranean, southern Africa and Australia (IPCC, 2001, p. 9).

Seasonal and daily climate variability will also be affected as will the frequency and intensity of a range of extreme weather events such as cyclones. Increases in daily maximum and minimum temperatures, and in the number of hot days, are very likely, with fewer cold and frost days. It is also likely that the difference between daily maximum and minimum temperatures will be reduced. More intense precipitation events are very likely in several places (increasing the risk of flooding), and increased summer drying is likely over mid-latitude continental interiors, with an associated increased risk of drought. Tropical cyclones are also expected to intensify, with more powerful winds and peak rainfall. Greater extremes of flood and drought are likely with the ENSO cycle (Pittock, 2003, p. 31).

Major climate changes for Australia

The worldwide climate trends described above are indicative of those said to be occurring in Australia. Australia is experiencing increases in average temperatures at nearly all locations, particularly overnight minima, but also in daily maxima, and more complex patterns of rainfall that change with location and time (Pittock, 2003, p. 47).

Australian average temperatures have risen by 0.7°C during the past century, with the past decade seeing the highest recorded mean annual temperatures. There has been a commensurate increase in the frequency of very warm days, and a decrease in the frequency of frosts and very cold days. Night time temperatures have risen faster than those during the day (Pittock, 2003, p. 47).



The year 2005 was the warmest on record for Australia (Australian Bureau of Meteorology 2006, cited in Steffen, 2006). The annual mean temperature was 1.09°C above the 1961-1990 average, and the average daily maximum temperature was 1.21°C above average, making for exceptionally warm daytime conditions. Higher than average temperatures were observed throughout the year and throughout nearly all parts of the country, but the austral autumn was especially warm. The largest Australian mean monthly temperature anomaly ever recorded occurred in April 2005, with a monthly mean of +2.58°C above the 1961-1990 average.

The 2005 temperature record in Australia was particularly significant. It easily exceeded the previous 1998 record anomaly of +0.84°C. Many of Australia's warmest years (such as 1988, 1998 and 2002) had temperatures boosted by significant El Niño events. However, no such event occurred in 2005, making the record warmth even more unusual. The 2005 record continued the multi-decadal trend in which all but four years since 1979 have been warmer than average.

Trends in rainfall are more difficult to determine although some observations show that there have been strong increases in the North West but decreases over SWWA, and much of the south-east and east coast. The most significant change appears to have been a decline in rainfall over the winter dominated region of SWWA, where from 1910 to 1995 winter rainfall has declined by as much as 25 per cent, mainly during the 1960s and 1970s. This abrupt

change in winter rainfall is not necessarily uncommon and has occurred in other parts of Australia. The reason for such abrupt changes is not entirely understood, but is presumed to be largely a natural phenomenon (Pittock, 2003, pp. 48-50).

There is some evidence of long term variations in storm frequency and tropical cyclones, which indicates that while there has been a decrease in the number of tropical cyclones from 1969 to 1996, there has been an increase in the frequency of particularly intense tropical cyclones (IPCC, 2001, p. 597).

The average sea level rise for Australia during the past 50 years is about 20 mm per decade, which generally concurs with estimates for global sea level rise (Rintoul *et al.* 1996; Salinger *et al.* 1996 cited in Pittock, 2003, p. 53).

Impacts of climate change in Australia

Due to uncertainty about the climate system, it is difficult to make specific predictions about the impacts of climate change on various community, industry and biological systems. In most cases impacts are estimated based on a range of scenarios about changes to temperature, precipitation and sea level rise.

For Australia, specific vulnerability and adaptation to past climate change is not well understood. While some past sectoral adaptations can be linked generally to climate change, there are in fact few where a direct link can be made. Much of the published literature describes 'likely' vulnerability and adaptation rather than that which has been observed.

However, many of Australia's community, industry and biological systems are considered to display significant vulnerability to climate change, and not surprisingly, varying adaptive capacities.

Water resources

Australia currently faces widespread water shortages, particularly in SWWA where rainfall, run-off and streamflow have dropped well below average (Preston and Jones, 2005, p. 25). In many cases climate change is likely to exacerbate this shortage through increased temperatures and possibly lower rainfall combined with more frequent ENSO events.

Adelaide and Perth, which typically receive lower rainfall and experience high evaporation rates, are experiencing particularly dry conditions prompting implementation of increased water restrictions to reduce consumption.

Water consumption in Australia is dominated by the agricultural sector, accounting for close to 67 per cent of the country's water use. Nearly half of this is used for pasture production, mainly in the Murray Darling Basin. Based on current projections it is expected that within 20 years, reduced flows and increased salinity in the Murray Darling Basin will result in Adelaide's water supply failing World Health Organisation Standards two days in five.



Given current projections of growth in our major cities, water planners believe that a 25 per cent reduction in per capita water use is required to maintain adequate supply to cities in the coming decades. Climate change could well impact on this timeline and put further pressure on an already stretched resource (DCC, 2005, pp. 61-64).

Biodiversity

The impact that climate change has had on biodiversity in comparison to other factors such as grazing and altered fire regimes following European settlement is poorly understood. However, certain trends can be linked to climate change.

A marked increase in woody biomass at the landscape scale has been reported for a number of environments. In rangelands this is known as a woody weed problem. While not the primary cause, atmospheric change is likely to have been involved in causing this phenomenon (Archer *et al.* 1995 cited in Pittock 2003, p. 54).

In some areas of the Northern Territory, expansion of tidal creek systems has occurred since the 1940s bringing saline water into freshwater wetlands. This has had dramatic effects on the vegetation of these freshwater wetlands. Again, these changes probably have multiple causes, but both sea level rise and increased rainfall may also have contributed (Woodroffe and Mulrennan, 1993; Bayliss *et al.* cited in Pittock, 2003, p. 55). The DCC has recently commissioned work to develop tools to assess the vulnerability of coastal wetlands in the Gulf of Carpentaria to climate change (Elliot *et al.* unpublished, June 2005).

One of the most visible (and well documented) climate impacts on biodiversity has been a global increase in the number and scale of coral bleaching events. In 1998, tropical sea surface temperatures were the highest on record, topping off a 50-year trend for some tropical oceans (Reaser *et al.* 2000 cited in Pittock, 2003, p. 57). In the same year, coral reefs around the world suffered the most extensive and severe bleaching on record, with mortalities following these events being higher than any in the previous 3,000 years (Aronson *et al.* 2002 cited in Pittock, 2003, p. 57). During a bleaching event in 1991-92, average daily seawater temperatures of the inshore fringing reefs of Magnetic Island on the Great Barrier Reef exceeded 31°C for 16 days. Temperatures again exceeded 31°C for 12 days during a similar event in 1993-94 (Pittock, 2003, p. 57).



Other pressures on biodiversity include the effects of increasing temperatures on alpine habitats and species, and the spread of weeds and feral animals favoured by higher temperatures. A summary of some current and future impacts of climate change on

Australia's biodiversity can be found in *Climate Change Impacts on Biodiversity in Australia—outcomes of a workshop sponsored by the Biological Diversity Advisory Committee, 1–2 October 2002* (Department of Environment and Heritage, 2003).

Options for adaptations by natural systems to cope with these types of pressures and the timescale dictated by climate change are likely to be limited. Plants and animals confronted by changing environmental conditions tend to be replaced by better suited species. Consequently there is a need for human intervention to facilitate adaptation responses for natural systems (DCC, 2005, pp. 70-71).

Agriculture



The agricultural sector is considered to have displayed a reasonable level of adaptive capacity to climate change. Farmers have expanded the coping range of agricultural crops and livestock by

breeding strains more tolerant to a wider range of climatic conditions. Furthermore, practices such as irrigation and pest control have further increased their resilience. Future climate change may in fact assist some agricultural production. For example, in a scenario where temperatures increase between 3.0 to 4.0°C, should sufficient increases in precipitation occur, wheat yields are predicted to increase. However, under less favourable precipitation scenarios, these increases would not be expected (Preston and Jones, 2005, p. 26).

Climatic extremes can inflict significant damage on agricultural industries. The 2002/2003 drought provided an example of agriculture's dependence on climate. Farm output fell by about \$3 billion and the Department of Treasury estimated that Gross Domestic Product was one per cent lower than it would have been had the drought not occurred (DCC, 2005, p. 48).

Projected temperature increases will stress livestock, leading to reductions in milk production even with warming of only 1.0°C. Decreases in rainfall will lower the quality of native pastures, and pests such as ticks, which may benefit from warming, will reduce cattle productivity (Preston and Jones, 2005, p. 24). Horticultural and cropping industries are also likely to be adversely affected by increased temperature, decreased rainfall and an increase in the incidence of extreme weather events, all of which will limit the capacity for plant growth in some regions. The impact on these industries will vary from place to place, with industries in some places already considered to be close to their threshold limits in terms of adaptive capacity (DCC, 2005, pp. 52-53).

Forestry

Australia has about 164 million ha (or 22 per cent) of its land area classified as forest. Of this, about one per cent is plantation forest and seven per cent native forest for timber production. Nationally, land clearing exceeds plantation establishment, although plantations are expanding at about 50,000 ha per year.

Climate change is anticipated to affect forest plantations and native forests through reduction in rainfall in the southern parts of Australia where the bulk of forest production occurs. Severe storm events are likely to increase erosion; temperature increases are likely both to extend the distribution of some pests and diseases and have a negative effect on soil moisture balance. A significant threat to forests, particularly pine plantations, is the projected increasing frequency of bushfires (DCC, 2005, p. 54).

However, the IPCC's Third Assessment Report (2001, p. 595) states the net impact of climate change on tree productivity, forest operational conditions, weeds, diseases, and wildfire incidence is not clear.

Fisheries



Fishing is heavily climate dependent—particularly wild catch. Research suggests that the recruitment and migration patterns of some fish species are sensitive to factors such as winds, ocean currents and temperature, and rainfall. Species such as Atlantic salmon, Pacific oysters and abalone are known to be highly temperature sensitive, and the Atlantic salmon population in southern Tasmania is currently at the edge of its heat tolerance.

The sector is likely to be impacted directly by rising water temperatures (which could reduce the availability of cold-water fish) and changes to other elements of the oceanic ecosystem. A potential decline in plankton and fish larvae could see a reduction in ocean biodiversity, including in fish and marine mammals.

Approximately 40 per cent of species of coast, estuarine and continental shelf fish are 'temperate endemics' that congregate in specialised habitats. Climate change could have a significant impact on the viability of these endemic species in Australian waters. A weakening of the Leeuwin Current off Western Australia could jeopardise the \$260 million western rock lobster fishery, which is Australia's single largest fishery (DCC, 2005, p. 57).

Again, the IPCC's Third Assessment Report (2001, p. 595) suggests that the impact on Australia's fisheries cannot yet be confidently predicted.

Public health

Assessing the implications of climate change on public health is difficult because of the complex interactions between climate, the environment and a number of other socio-economic factors (Preston and Jones, 2005, p. 26).

In general, continued climate trends are expected to increase heat stress mortality, the incidence of tropical vector-borne diseases such as dengue, and urban pollution-related respiratory problems (IPCC, 2001, p. 596). A recent study *Human Health and Climate Change in Oceania: A Risk Assessment* (2002) highlighted the following key findings.

- Extreme temperatures contribute to the deaths of about 1100 people aged over 65 each year in 10 Australian cities. Without adaptive measures, the projected temperature increase for the next 50 years may result in a substantial increase in heat-related deaths.
- Extreme rainfall events are expected to increase in almost all Australian states and territories by 2020. Annual flood-related deaths and injuries may also increase by up to 240 per cent in some places.
- The 'malaria receptive zone' may expand southwards. However, malaria itself is not a direct threat under climate change, so long as a high priority is placed on prevention.
- Suitable conditions for the transmission of dengue may expand in the south-west, putting a larger number of people living in northern Australia at risk of dengue infection (a total of 0.3-0.5 million in 2020, and 0.8-1.6 million in 2050). This doesn't necessarily mean an increase in dengue cases, provided there is continued expansion of vector control and public health surveillance, and quarantine efforts to ensure a secondary dengue vector does not become established.



- Increasing temperatures and rainfall variability are predicted to increase the intensity and frequency of food-borne and water-borne diseases. Due to poor living conditions and access to services, there may be a 10 per cent increase in the annual number of diarrhoeal admissions among Aboriginal children living in central Australia by 2050.
- Summer-time food-borne infections (such as salmonellosis) may show longer-lasting annual peaks.
- The public health consequences of the disturbance of natural and managed food-producing systems, of rising sea-levels, and of population displacement for reasons of physical hazard, land loss, economic disruption and civil strife may not become evident for several decades (McMichael *et al.* 2002, pp. 3-4).

Some studies suggest that due to its relatively high adaptive capacity, Australia's public health sector is considered to have low vulnerability. However, there are particular groups such as the country's Aboriginal population, recent migrant populations, and those on low incomes that may have higher vulnerability as a result of limited access to funds and health services (Preston and Jones, 2005, p. 27).

Settlements and infrastructure

Aspects of human settlements that have received most attention in climate change literature include energy, the built environment of the coastal zone, transportation, and tourism and recreation. Settlements generally display low vulnerability to gradual climate change and variability. However, they are often vulnerable to extreme weather events such as storm surges and cyclones.

Australia's energy sector may be one of the first sectors to respond to climate changes. For example, impact assessments indicate that just a 1.0°C increase in average temperatures would be sufficient to increase peak demand for electricity in Adelaide and Brisbane, and reduce transmission efficiency.

Australia's coastal zone is of particular concern given the high concentration of people, commerce, and industry in this zone. Climate modelling suggests that storm winds, including those associated with tropical cyclones, may become more intense with a warming of 1.0 to 2.0°C. This combined with sea level rise would cause greater storm surges during storm events and an increase in flooding. Sea-level rise and storm events also contribute to coastal inundation and beach erosion, which may adversely affect popular tourism and recreation areas (Preston and Jones, 2006, p. 28).

CLIMATE CHANGES FOR SOUTH WEST WESTERN AUSTRALIA

The remainder of this report seeks to address that to date the *observed* impacts of past climate changes on communities, industries and ecosystems are not well understood. While the nature of the changes is well documented, and most literature discusses future potential impacts, how these changes have been expressly manifest, realised and dealt with up to now has not generally been assessed.

SWWA is already feeling the effects of climate change, having experienced a decrease in winter rainfall during the past 30 years and temperature increases during the last century. Studies by the IOCI suggest the changes are associated with a shift in the large scale, global atmospheric circulation, which is consistent with changes projected by global climate models. However, IOCI also points out that there is insufficient evidence to link these changes to the enhanced greenhouse effect alone, and that they are more likely a result of this phenomenon and natural climate processes (DCC, 2005, p. 87).

Features of climate change

Temperature

The annual mean temperature averaged throughout Western Australia has increased by a little more than 0.8°C since 1910. This compares with the global average increase of 0.6°C during the 20th Century. Daily minimum temperatures have increased by more than the maxima. Averaged throughout the State, the warming following 1950 has been greatest in winter and spring and the least in summer. While these temperature departures may seem relatively small, a 1.0°C increase in mean temperatures is equivalent to many southern Australian towns shifting northward by about 100 kilometres (Bureau of Meteorology, Climate Summary, 2006)

Virtually everywhere in Western Australia has warmed during the last century (**Figure 1**). However, trends have not been uniform over time, with the late 20th Century showing the most consistent period of warming (see Figure 2). This pattern is consistent with trends in other parts of Australia.

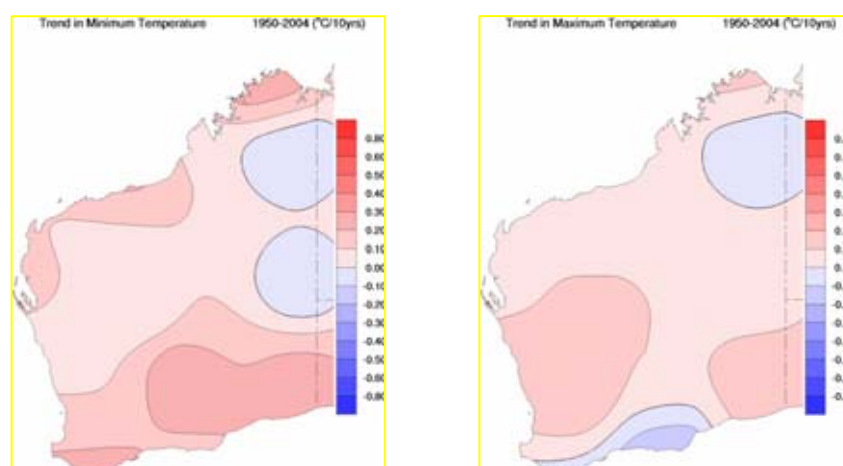


Figure 1 Trends in daily minimum and maximum temperatures, 1950-2004.

Source: Bureau of Meteorology.

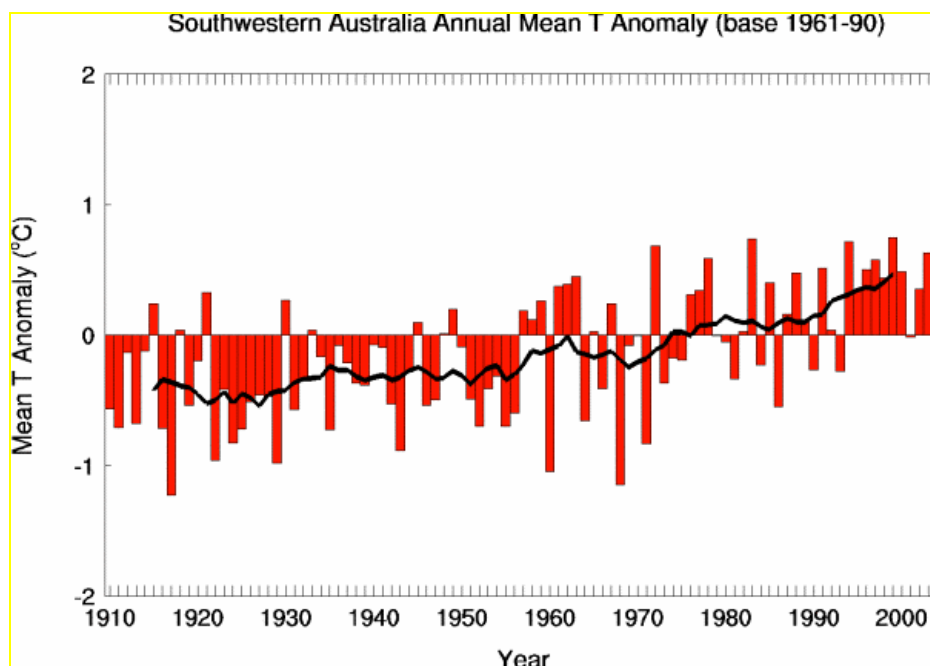


Figure 2 Trends in mean annual temperature, averaged over SWWA, 1909-2004.

Source: Bureau of Meteorology.

The enhanced greenhouse effect is most likely responsible for much of the observed warming, but natural causes have also contributed. It is also likely that other human actions such as changes in land cover have led to temperature increases in some parts of SWWA.

Model-based projections for temperature with increasing greenhouse emissions indicate a continued warming trend for most of the planet. CSIRO research shows temperature rises for the south of the State and nearer the coast of 0.1 to 0.65°C each decade from 1990 to 2070 (IOCI, August 2005).

Rainfall

Rainfall in SWWA was once considered to be the most consistent and reliable of anywhere in Australia. The region derives much of its annual rainfall from passing cold fronts and associated storms, which are typical features of a winter synoptic pattern and form part of the atmospheric circulation. However, annual rainfall in SWWA has declined by about 10 per cent since the mid-1970s, with a noticeable shift toward drier winter conditions continuing to this day. Not only has the number of winter storms decreased but those that do eventuate generally bring less rainfall.

This sharp drop in rainfall occurred at the same time as a global change in the atmospheric circulation. The past few decades have been characterised by an increase in average sea level pressure in Australian latitudes, with decreases in pressure further south. Some of the largest pressure increases occur over SWWA and are associated with the decline in rainfall (IOCI, August 2005).

Regionally, the greatest rainfall decline has occurred along the lower west coast, with smaller decreases also observed in agricultural districts. Percentage changes in winter rainfall (May to October) are shown in **Figure 3**. There has also been a shift in mean rainfall contours towards the west coast over the past three decades, especially for the high rainfall zones.

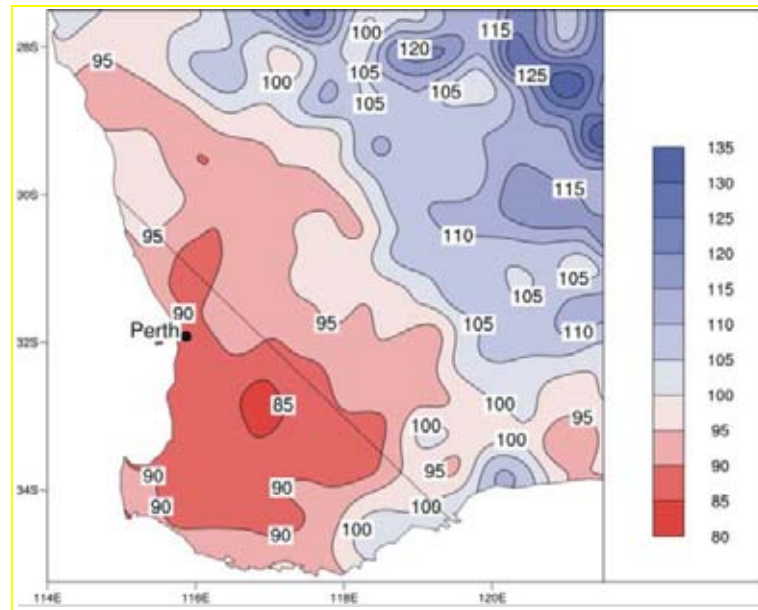


Figure 3 Average May to October Rainfall, 1976-2001 as a per cent of Average May to October Rainfall, 1925-1975.

Source: Bureau of Meteorology.

Time-series plots of May to October rainfall are shown for Jarrahdale (Figure 4), Merredin (Figure 5) and Lake Grace (Figure 6). The strongest change is seen in the Jarrahdale plot, where the inter-annual rainfall variability (and seasonal mean) has decreased since about 1975. This is evident as a step change rather than a trend for the full period, and is typical of the higher rainfall regions of SWWA. Average seasonal rainfall for the years before and after 1975 is also shown. The average May to October rainfall is less for the years since 1975, even for Merredin and Lake Grace (which show a weak rainfall trend over time).

Most of the decline has occurred early in the growing season of winter rainfall period (i.e. May to July), with little trend in spring rainfall (see for example Corrigin in Figure 7). Trends in late season rainfall (August to October) have been small. Summer rainfall has generally increased, especially in eastern agricultural areas (Figure 3) though the trends are not large and inter-annual variability remains high.

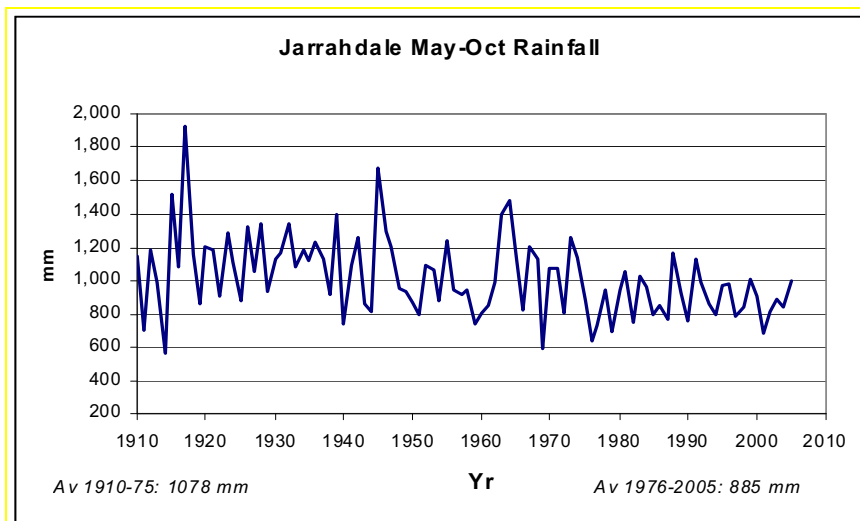


Figure 4 May to October Rainfall for Jarrahdale since 1910, plotted from Patched Point Database Records.

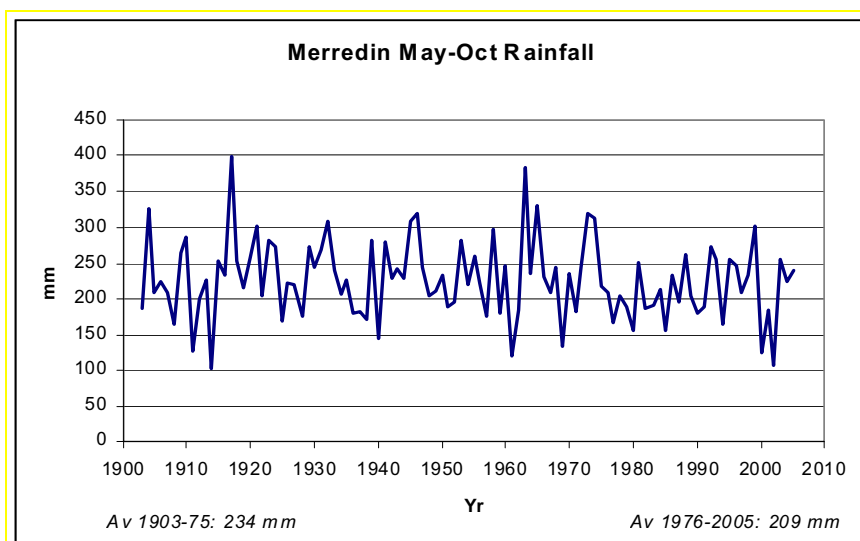


Figure 5 May to October Rainfall at Merredin since 1903, using PPD Data.

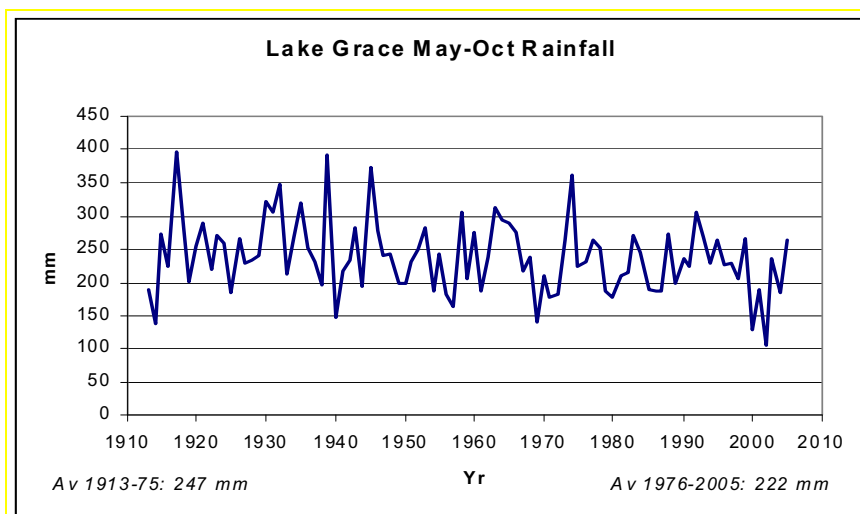


Figure 6 May to October Rainfall at Lake Grace since 1913, using PPD Data.

Decreases in average May to July rainfall have been up to 15 per cent in some locations, with fewer very wet years (i.e. May to July rainfall in the wettest 20 per cent of all years). Additionally, seasonal rain during the past three decades has been more likely to be below the long-term average, with the occurrence of seasons that are well above average being less frequent in recent decades. In contrast, the South Coast's May to July rainfall has remained generally steady.

Another feature of rainfall in the past 30 years is that there have been fewer rain days each year and less rainfall per rain-day. The proportion of May to July rainfall that comes from daily rain events of less than 10 mm has increased and the region sees less rainfall from heavier events.

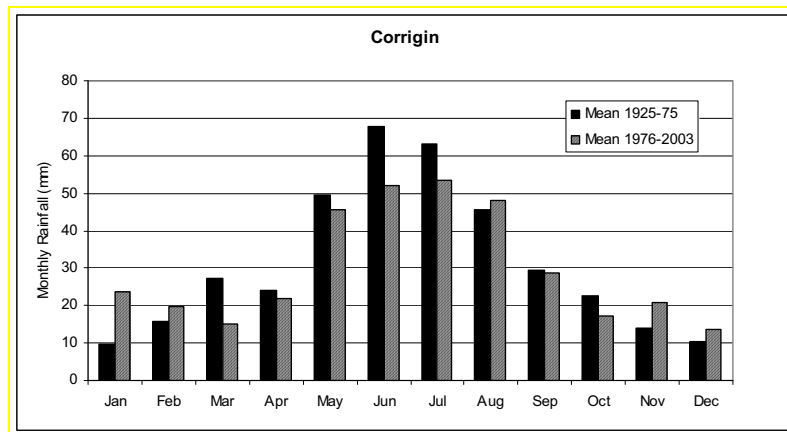


Figure 7 Average Monthly Rainfall for Corrigin, 1925-1975 (Full Columns) and for 1976-2003 (shaded columns).

The run of dry years is unusual when compared with historical records, and also with 1,000 years simulations of Western Australian climate in computer models. However, these dry events are broadly consistent with current climate change projections of rainfall over SWWA. The observed rainfall decline is of similar magnitude to that projected but the timing differs.

There are many possible causes for these changes but the underlying drivers are believed to include increased greenhouse gases and the fact that the climate system undergoes natural fluctuations on the scale of several decades.

Projections for the future, suggest that the influence of increasing concentrations of greenhouse gases will become more dominant causing a further decline in rainfall due to higher pressures and fewer storms (IOCI, August 2005). However, there are considerable variations between different models' predictions of the magnitude of the expected decline (IOCI, 2002, p. 19).

Sea level rise

Fremantle tide data show that mean sea level rise has increased almost 20 cm at a rate of 1.54 mm per year since 1897 (**Figure 8**). This is similar to that observed globally, which is estimated to range between 1.1 and 1.8 mm per year. The rising sea level has been attributed to thermal expansion of the ocean due to increased warming.

Superimposed on this increasing trend, the rate of sea level rise has changed due to the inter-annual variability caused by the ENSO phenomenon. As a result the mean sea level rise remained almost constant between 1952 and 1991, and has increased by almost three times the global rate since 1991.

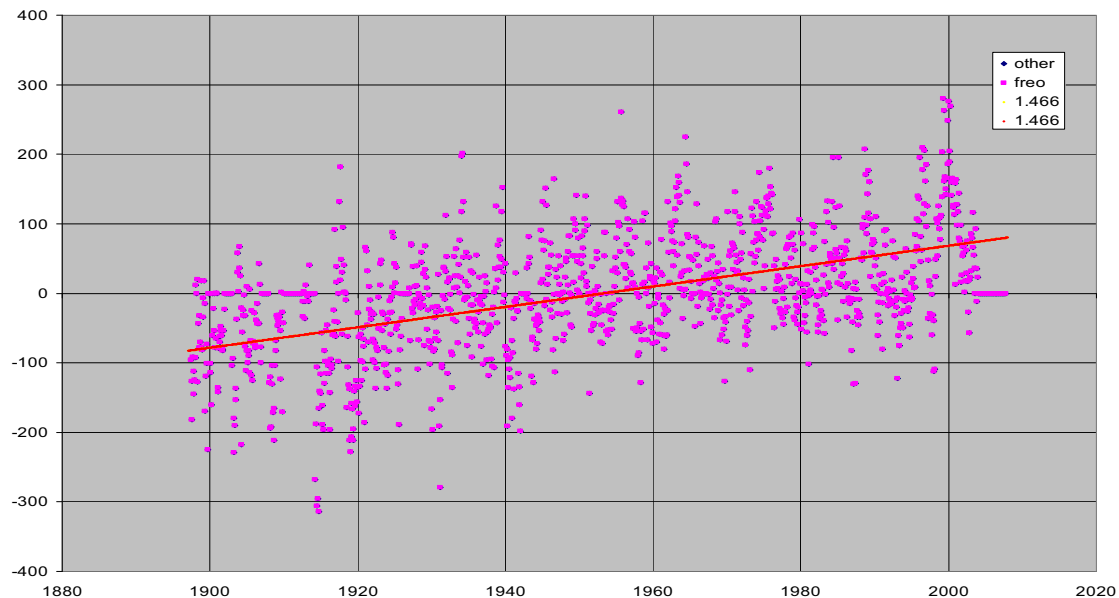


Figure 8 Sea Level Rise at Fremantle based on Monthly Mean Sea Level Observation, 1897-2003.
Source: Fremantle Ports Tide Gauge.

The major impact of sea level rise in Western Australia is on beach stability and potential inundation of low-lying coastal regions under storm conditions. Under storm conditions, sand is eroded from beaches and deposited offshore under the combined action of waves and the higher water levels cause by storm surges. It is generally accepted that a one centimetre rise in mean sea level will be accompanied by a loss of about one metre of beach. These effects are confirmed by widespread erosion of SWWA beaches in 2003 and 2004.

It is generally accepted that, due primarily to ongoing ocean warming and resultant thermal expansion, global mean sea level will continue to rise during the 21st Century. The predicted rise is up to 0.30 metres by 2040 resulting in possible beach erosion of 30 metres (IOCI, 2005).

IMPACTS AND RESPONSES

The remaining sections of this report detail impacts of climate change experienced by different sectors in SWWA and the ways in which they have responded. They also demonstrate that a number of sectors are yet to deal with the impacts of climate change and that several have only recently become aware of the need to deal with it in the future. The sections highlight how other factors such as land and water degradation, economic pressures and changing social attitudes are driving adaptation responses, with climate change emerging as one of several additional pressures facing people, industries and ecosystems in the region.

Each sector has undertaken some assessment of needs in relation to planning for future climate impacts. For most sectors, these are relatively new considerations and many do not have ready answers or information on which to base decisions. In this regard the study has been particularly important in bringing climate change to the table. For a number of sectors this is the first time policy and decision makers have addressed climate change in any substantially formal way.

The study has also attempted to shed more light on the wider community's perceptions of climate change through a series of community consultation sessions. These focused on past and future climate changes and sought to establish the extent to which people have so far planned, and intend to plan, responses to climate change. A summary of findings from the sessions follows.

Public perceptions and observations

Broad acceptance

There was broad acceptance at the consultation sessions that climate change is a reality. Few, if any, people came to the consultation sessions needing to be convinced as to whether it was happening or not, nor were counter-arguments put forward disputing global climate change science. This may indicate broad community acceptance of climate change because of their personal observations and experience. However, it was frequently raised that much of the change was probably a result of natural variation, as well as having been induced by human activity, and there was some uncertainty about the extent to which each of these factors has driven past climate changes. Lack of scepticism was not universal, but such views were muted possibly because they were a minority opinion or in deference to expert opinion.

Most of the people and sectors represented at the sessions seemed to be coping satisfactorily over short time frames and did not appear to have thought much about factoring adaptation to a non-stationary climate regime into long-term decisions. Many spoke of mitigation actions, but did not believe they needed to develop adaptation strategies. When people hear the evidence demonstrating the region has already experienced climate change and then upon reflection recalled some instances of adverse impacts, they seemed to conclude that they must have adapted reasonably well. There were few impacts and behavioural changes attributed directly to climate change, with people feeling that because of ongoing prosperity, well being and environmental health during the past 30 years, any impacts must have been within the region's coping capacity.

Declining rainfall has driven responses to climate change

In the few instances where specific adaptation responses could be identified, these were more commonly linked to other events, community demand and economic drivers, rather than a conscious acknowledgement of long-term climate change. For example, the agricultural sector has maintained productivity in what we now know is a drying climate by adopting new technology and improving management practices. Farmers noted these responses but linked them more to concerns about maintaining productivity and profitability in the face of evolving technology and market conditions, and ongoing climate 'variability' rather than what might now be called 'climate change'. Their primary motivation for change was improved efficiency to maintain global competitiveness.

Some farmers are now aware of the region's longer term rainfall decline as a result of climate change, and acknowledge that adoption of new technology has essentially 'masked' the identified drying trend since the mid-1970s (and more recently since 2000). With regard to agriculture and forestry there were indications that at some locations these industries may be nearing thresholds in terms of their capacity to maintain optimum productivity in the face of increasing dryness or climate adversity, particularly agriculture in parts of the Ravensthorpe area and forestry in parts of the Esperance area.

The water resources sector has made the most significant and direct responses to SWWA's climate changes. Representatives from this sector confirmed that the region has experienced significantly less rainfall during the past 30 years, that wet (i.e. well above average rainfall) winters have virtually disappeared, that rainfall events were less reliable and those that did occur were generally lighter, and that much of SWWA was suffering water supply shortages as a result of decreased streamflow and inflow into dams. As a result the State has shifted its reliance on water supply during this time from primarily surface water to a greater emphasis on groundwater and is investing significantly in alternative sources such as desalination. For this sector, adaptation is a direct acknowledgement that rainfall has shown abrupt decreases in the mid-1970s and again around 2000, which has resulted in significant planning and investment in alternative water resource management actions and awareness-raising activities. In effect the water resources sector has identified its vulnerability to climate change and planned accordingly.

While reduced water supply has been observed by the State's water resource sector during the past 30 years and adaptation responses have been developed to ensure ongoing supply, other sectors reliant on that supply have also experienced impacts. However, many of these seem to have been perceived only more recently. They include:

- impacts on sporting grounds as a result of water restrictions;
- increasing salinity of dams that support horticultural operations where some dams are not receiving sufficient rainfall to flush salt out;
- increased stress on native vegetation and changed fire behaviour;
- increasing competition for groundwater between water supply needs, ecosystem needs and forestry operations; and
- increased algal blooms in some waterways as a result of nutrient enrichment exacerbated by higher temperatures and decreased flushing.

While climate change may have contributed to several of these impacts, climate variation is also thought to be a factor, as are a number of other land and water degradation effects. Participants acknowledge the impact of unsustainable practices such as over-clearing native

vegetation, poor fertiliser management, insufficient planning, and pests and diseases, and that climate change is emerging as an additional pressure on some already degraded systems.

Increased media attention is a good yardstick for growing community concern and the State's media is picking up climate change issues for SWWA, particularly in relation to water shortages. Government investment in desalination, divided community opinion about inter-regional transfer of groundwater resources and the plight of the State's farmers in the face of the driest season in 100 years are capturing public and media attention.

Mitigation responses

While adaptation responses may not have been common during the past 30 years, it is evident that there has been awareness of global warming and thus a push for mitigation strategies, particularly during the last five to 10 years, in the resource sector.

Many industry organisations understand growing community concern about global climate change, and have acted accordingly. The Chamber of Commerce and Industry highlighted that several of its members have already assessed their relative level of risk or exposure to climate change. In many cases they have not waited for government research or policy direction, but taken the initiative themselves as part of business decision making. This has included active steps to offset or sequester carbon emissions, to manage sites to optimise water use efficiency, or working out how best to operate in current and possible future government policy environments. Industry organisations believe government has an important leadership role to play by encouraging industry to take action, but not create trade disincentives.

Alcoa has a global Climate Change Policy to improve energy efficiency at all of its operations through implementing best practice technologies to reduce greenhouse gas emissions. It is developing new technologies to reduce emissions such as residue carbonation at its Kwinana refinery and is partnering Alinta Limited to build energy-saving cogeneration power plants at Alcoa's refineries. It is predicted that cogeneration technology at the Pinjarra and Wagerup refineries could avoid the release of more than 1.8 million tonnes of greenhouse emissions compared with conventional electricity generation.

Another example can be found in Gorgon Project Joint Venture's commitment to greenhouse emissions management. Gorgon has developed a proposal that will see the disposal of approximately 2.7 million tonnes of carbon dioxide per year by means of underground injection into a deep aquifer. This action is based on the organisation's awareness of growing community, industry and government concern about global climate change, which has essentially been integrated into its business decision making.

The State's Water Corporation has also established a number of greenhouse gas mitigation strategies, including a recent strategy to become carbon neutral. The Corporation joined the Greenhouse Challenge Program in 2001/2002, and by 2003/2004 reported a greenhouse gas abatement of 110, 000 tonnes of carbon dioxide equivalent, or more than 25 per cent of its gross emissions for that year. This was achieved through:

- improving energy efficiency;
- increasing the use of renewable energy;
- the capture and combustion of methane;
- fuel switching;
- establishing an Energy Management Unit;

-
- carbon sequestration; and
 - a water education media and enforcement campaign (Humphries *et al.* 2005)

Woodside Petroleum Ltd has also joined the Australian Government's Greenhouse Challenge, under which it has:

- committed to investing \$211 million on technical abatement measures;
- identified a projected reduction in emissions of approximately 38 million tonnes carbon dioxide equivalent against 'business as usual' between 2002 and 2022; and
- won awards for greenhouse abatement in 2001, 2002 and 2005.

Woodside is also a foundation sponsor of the Cooperative Research Centre for Greenhouse Gas Technologies, and its sponsorship supports projects such as the first carbon dioxide geo-sequestration project in Australia, being conducted in the Otway Basin.

Perceived temperature changes

Participants confirmed the temperature changes highlighted by IOCI, with people generally feeling that the weather had become hotter and drier during the past 30 years, with longer but milder summers. Comments were frequently made that the sun seemed to have more 'bite' to it and that the duration of warmer weather into autumn had lengthened. There were several comments made that the lead up to summer seemed to be slower, with November and December being generally cooler, but the incidence of unusually hot days during those months being higher. In fact, participants felt that the number of heat wave days (days above 35°C) generally had increased throughout the summer period. This concurs with recent trends observed by the Bureau of Meteorology with 2005 being the warmest year on record. Also in relation to lengthening summer-like conditions, autumn 2005 was particularly warm. April had the largest Australian mean monthly temperature anomaly ever recorded, with a monthly anomaly of +2.58°C breaking the previous record of +2.32°C set in June 1996 (Bureau of Meteorology, 2006).

An anomaly in relation to temperature for SWWA that was highlighted at several sessions was the increasing incidence of frost events in agricultural areas. Scientific information suggests daily minima are increasing throughout most of the region, but farmers reported the number of frost events causing damage to crops appears to be increasing. This issue may require further research by the agricultural sector.

Perceived rainfall changes

In relation to rainfall there was a common view among participants that the break of the season now occurred about two weeks later in the year than in past times and that the number of particularly wet years had decreased. One farmer reported that when he moved to a sheep farm in Western Australia in the mid to late 1980s, historical records showed "*the average rainfall was 21 inches, but since taking up the farm there hasn't been one year when the rainfall reached 21 inches*". In contrast, another farmer's rainfall records at a particular location did not support the drying trend, but showed that the trend for growing season rainfall had remained fairly flat during the past 40 years. This farmer's records showed an upward trend in yields over the same period because of improved management and some very rough thresholds were discernable. Low yielding years in this area were associated with growing season rainfall of less than 250 mm and greater than 325 to 350 mm.

Despite such contrasts there was a feeling that winter rainfall was patchier and that the frequency of summer thunderstorms had increased. A number of farmers noted that dams were emptier during winter and that summer rainfall fed by the remnants of northern, tropical weather systems now seemed more common.

There was general consensus that the frequency of extreme rainfall events had increased, particularly storms causing flooding. People could recall a number of relatively recent events where public and private infrastructure had been damaged as a result of floods; for example, recent floods at Lake Grace last year and at Greenough this year. A number of people at coastal locations expressed concern about this trend given rising sea levels and the impact storm surges may have on coastal infrastructure and communities.

The incidence and duration of drought was commonly highlighted as occurring more frequently. Agricultural areas, particularly in the north eastern and south-eastern wheatbelt have experienced extensive drought, with Exceptional Circumstances declarations covering various parts of the region having been made every year since 2000. This extended dry period has a significant effect on agricultural businesses and in turn adverse impacts for the rural towns that support them. The region is in the grip of its worst drought on record, experiencing its driest start to winter in 2006.

Recent modelling by the Department of Agriculture and Food (van Gool and Vernon, 2005) shows that if drying and warming trends continue as projected, agriculture could change substantially, with cropping becoming an unviable land use over large areas and farm profits in vulnerable eastern and north-eastern areas likely to be reduced by more than 50 per cent despite profit saving adjustments that can be made. This will have major social and economic implications in affected areas and consequentially financial implications for Government. By way of example, Exceptional Circumstances declarations for drought, made for the first time in WA during the past five years, have had direct business and family support costs of \$80 million. These costs however are dwarfed by estimated production losses of around \$2.7 billion in the declared areas over the same period.

Extended dry periods also have impacts on other business that support agriculture. *The West Australian* (Petchell, 2006, p. 18) reported the impact the current extended dry spell is having on the fertiliser industry for example. Fertiliser companies anticipate having to carry large quantities of stock through to next year as a result of decreasing demand from drought-affected farmers, which will substantially increase their storage costs. The same article highlighted how livestock feed suppliers were struggling to keep up with demand due to extensively dry paddocks throughout the State's agricultural areas. *The West Australian* also ran numerous stories throughout 2006 outlining the plight of farmers, reporting significant crop losses, and that in several areas farmers did not even bother to sow crops.

Other observed changes and impacts

Session participants indicated that wind patterns also seem to have changed, with local wind conditions reportedly becoming more erratic (or less predictable). Some participants highlighted activities that could previously be undertaken with confidence on the basis of predictable local winds such as burning and boating. However, local wind predictability appears to have declined making it difficult to schedule these activities for the most appropriate times. This was noted at coastal locations of Albany and Geraldton, and inland at Katanning and Ravensthorpe.

There was general concern about the impact of climate change on biodiversity. This ranged from concern about the effects of damage to vegetation, how climate change may improve conditions for pests and weeds, and increases in the incidence of fires, and effects on the

ecosystem services that various plants and animals provide. People reported damage to vegetation in particular locations but were unsure about the extent to which this was climate related. It would be fair to say that other than the Albany session, the issue of the impacts of climate change on biodiversity was not generally raised, except in relation to fire behaviour.

While there is evidence to suggest the water resource and agricultural sectors have already adapted to climate change, other sectors seem not to have substantially factored climate change into their planning and operations to date. This is perhaps because the effects so far have not been felt. However, some lifestyle-related sectors, particularly in the area of sport and recreation are beginning to look at climate change as a consideration for future planning, possibly as a result of more recent observations of climate change impacts and growing public awareness. By way of example, the Department of Sport and Recreation included a session on climate change in the program for its annual Active Conference in September 2006, which was partly due to its involvement in Phase One of this study.

Future climate change

The community consultation sessions highlighted the great diversity of climate impacts that may need to be managed in the future; from maintaining outdoor recreational facilities in a drier climate to establishing infrastructure that can cope with rising sea levels. With the exception of water resources, the sessions did not reveal many sectoral efforts to assess coping capacity or thresholds in relation to climate change. This seems to be largely driven by uncertainty (as opposed to scepticism) about the issues and a lack of information on possible responses. Climate change was seen as a complex, amorphous subject, with people unsure about impacts, and the type of response and level of investment required.

People expressed the view that with good information and planning they would be able to develop strategies to deal with the future impacts of climate change. The sessions revealed increasing interest in future projections for climate change, particularly from sectors representing lifestyle, sport and recreation. Almost all sessions had people attend from these sectors. In particular these sectors are concerned about the impact of climate change on regional locations, where sport and recreation are integral parts of the social fabric of rural and regional communities. Comments were made that in recent times, town ovals and parklands were suffering as a result of drier conditions and that this trend was expected to continue. This presents particular challenges for local governments, which will need to plan for these impacts when considering future recreation and amenity needs.

These sectors also raised concerns about future health and safety impacts as a result of sea level rise. Surf life saving organisations anticipate greater coastal usage in the future and that this will increase the burden on their resources. This may be compounded by changes to ocean swells and currents. Sea level rise is potentially a major issue for SWWA, which is experiencing significant population growth at regional coastal centres such as Busselton, Bunbury and Mandurah and where coastal housing developments are booming. A number of people expressed concern about the future viability of these developments in the face of growing evidence for sea level rise and that this presents a major challenge for local governments and the Government's planning agencies. Industry participants also expressed concern about the impacts of sea level rise on development projects and existing infrastructure such as ports and the need for these to be engineered to withstand more intense storms and storm surges.

Among agricultural participants there were varied responses that seemed to depend largely on location. In some areas, participants felt they could cope with projected increases in temperature and decreases in rainfall, while others in perhaps more marginal areas felt it

would not take much of a change before farming for them becomes unviable. A common concern amongst farmers was that younger farmers are not well prepared for extreme events as conditions have been reasonably stable in many locations for so long, and technology has allowed increasing productivity. There was also a sense that people were not prepared to live at the extremes of human comfort any longer and that consequently less pleasant climatic conditions could have implications for small communities.

Members of the horticultural industry also expressed concern about the impact of future temperature changes on the quality of fruit and vegetables. Predictions for increased daily minima are a concern for industries which rely on cool mornings and warm days to improve colouration and sugar levels. However, despite predictions for warmer nights, recent observations suggest increased incidence of frosts and cool mornings. This was frequently reported by people during the study. Additionally, a recent article in the *West Australian* (Jerrard, S and Philip, M, 2006) highlighted how recent cool conditions have been good for fruit quality. However, the same article also described industry concern about declining water supplies, with one grower quoted as saying *"I've never known us to be irrigating in June and my family's been growing citrus for almost 100 years."*

Industry and resource sector participants expressed particular concern about ongoing access to water and how issues regarding competing access for water could be resolved. These sectors felt that industries could engineer their way around other climate impacts. They felt that technology would largely overcome climate impacts on workers and infrastructure. However, extreme weather events may pose particular problems for the industry and resources sectors. Extreme weather events require disaster responses which shift skilled labour away from new and ongoing industry developments. If the number of extreme events increases this could have an effect on the availability of skilled labour to progress industry projects.

Access to water was probably the single biggest concern people had in relation to future climate change. Farmers expressed concern about ongoing capacity to grow crops and water stock, the resources sector is concerned about future access to water and its discharge, tourism and recreation will suffer as a result of reduced water supplies, water dependent biodiversity will be adversely affected as will people through reduced ecosystem services and the importance of potable water for human consumption is not surprisingly a major concern.

Information requirements

The need for more information about climate change emerges as a key issue when discussing the subject with stakeholders. As previously mentioned people accept climate change as a reality but they don't yet fully understand the nature of it or its potential impacts. The consultation sessions suggest a reasonably high level of interest in knowing more about the issue, particularly future predictions, projections and scenarios.

Primary requirements for information that would assist adaptation to climate change were quite similar, with some specific differences reflecting the range of sectors represented at the sessions. The main climate issues people want information about include:

- projections for temperature increases, including the number of extremely hot days (days over 35°C) that are likely;
- rainfall projections including seasonal shifts;

-
- an assessment of water cycle impacts as a result of reduced rainfall;
 - predictions of sea level rise; and
 - some indication of the likelihood and timing of extreme events.

People primarily supported a web-based mechanism to receive information, plus a range of other methods. As well as information provision to support planning processes, people felt the issue of climate change generally deserves more attention in the public arena and that awareness raising would be an important activity.

A number of the sessions also raised the need for case studies and scenarios highlighting cross-sectoral issues as a result of climate change impacts. For example, how will a reduction in rainfall affect community water supplies and in turn water dependent industries; or what would happen to a small community if one of its major industries was dramatically affected by climate change. These scenarios would need to include some assessment of likely conflicts and how mutually beneficial responses could be developed.

Indicators for further work

A number of sectors were not well represented at the consultation sessions, including health, local government, planning, fishing and tourism. These sectors need to be better engaged to develop a more complete picture of climate change impacts throughout SWWA. However, these sectors are represented on the Action 5.5 Sub-committee and some information about them has been obtained from other sources outside the consultation sessions for input into Phase One and for planning Phase Two.

Sectors that appear to have particular interest in climate change, based on attendances at the sessions, are:

- primary industries such as agriculture, horticulture and forestry;
- water resources management;
- sport and recreation; and
- industry and resources.

Attendance at southern (Katanning, Ravensthorpe and Albany) sessions was high, and feedback on the outcomes from these sessions was also relatively high. This may suggest that further work would be well supported by community, industry and government organisations in these areas, particularly on the South Coast. Follow-up meetings have also been held with stakeholders at Ongerup and Mount Barker on the South Coast as a result of the consultation sessions.

The sessions may also have unearthed some interest among sectors that are becoming aware of a need to deal with climate change. For example, the surf life saving sector was interested in climate change which resulted in follow-up interest from people involved in coastal health issues.

In relation to Phase Two, the sessions suggest high level community interest in some key areas. Ongoing water shortage is a critical issue and the potential this has for creating conflicts needs to be assessed. A number of industry users emerged during the study including agriculture, horticulture, forestry and mining all of which will be competing with water for public supply, amenity value and for ecological requirements.

The study has also revealed growing community and Government concern about the impacts of sea level rise. These concerns appear to be growing in the face of almost unbridled development of coastal locations, with areas such as Mandurah, Bunbury, Busselton and Cockburn targeted for significant future growth. The study highlights that the State's planning agencies and local governments in particular need to address development in the context of climate change, which at present appears not to be a widespread planning consideration. Rising sea level also has potentially significant implications for the tourism industry, which is heavily reliant on natural coastal assets and infrastructure.

Through the study it has become apparent that the health, sport and recreation, and tourism sectors have similar concerns in relation to future climate change. Each sector is concerned about the impact of increasing temperatures on human comfort and well being, and the threat of declining water quality and supply similarly has implications for human use, amenity and wellbeing. An assessment of these variables between the sectors may well yield integrated strategies and mutually beneficial responses.

The study has also highlighted a general lack of understanding about the impacts of climate change on the State's biodiversity. This is not limited to SWWA with climate change impacts on biodiversity worldwide difficult to discern and attribute directly to factors such as increased warming and sea level rise. However, given the region is one of the world's 25 biodiversity hotspots and contains five of Australia's 15 biodiversity hotspots, it would appear an assessment of climate change impacts is needed.

WATER RESOURCES

Introduction

Water resources in Western Australia are part of the global hydrological cycle, involving masses of water in oceans, lakes, rivers, underground aquifers and ice. Circulations between these masses occur because of daily and local weather, seasonal and regional climate factors, longer global climate variations, cycles and changes, and, to a lesser extent, human use and disposal. On long time scales, global temperature changes have resulted in greater or less water being held in ice, and associated falls and rises in sea levels. Regional changes to precipitation alter surface runoff, stream flow, wetland levels and groundwater recharge.

Since the start of human settlement and agriculture, human use of water and landscape alteration have changed local and regional water resource quality and quantity. Human induced global and regional climate changes pose significant new challenges to water resource managers. Increased rainfall can produce soil erosion and damage infrastructure; decreased rainfall can reduce water availability to users and the environment. Higher temperatures normally increase evaporation, reducing soil moisture for agricultural crops, natural ecosystems and forests and reducing stream run off and groundwater recharge. In SWWA these impacts have been exacerbated by rapidly increasing population settlement and economic activity.

A drying climate results in less surface water



The main observed feature of climate change in SWWA during the past 30 years has been a significant decrease in average rainfall between May and October and a noticeable decrease in the number of high rainfall years. Higher average annual temperatures have also been recorded throughout SWWA.

Rainfall amount and intensity are understood to be significant factors for surface water supply and ground water recharge. In line with these principles, surface and ground water supplies in affected areas (those which rely on surface water from dams located along the Darling Scarp, groundwater from aquifers underlying the Swan Coastal Plain, and local supply schemes in affected parts of the wheatbelt) have been affected. The impact is not linear; the observed 10 per cent decline in average annual rainfall in SWWA has resulted in a several-fold larger decline in inflow into the Perth metropolitan reservoirs. In parts of SWWA a 10 per cent reduction in rainfall has caused a 50 per cent reduction in streamflow.

The non-linear reduction in streamflow occurs because rainfall needs to reach a certain threshold before streamflow can occur. For many SWWA rivers this threshold is related to the large water storage capacity of the soil profile—streams don't flow until the soil profile is saturated and water can no longer be absorbed but must flow along the surface. The large soil water storage in the soil profile means both less streamflow, but also that rivers start flowing later and for less time than would be the case with other soil types. Changing stream flow profiles affects water supplies and has major implications for the structure of rivers, in-stream ecology, riparian vegetation and stream salinity (IOCI, 2005).

Reduced streamflow has led to increased use of groundwater in the Perth region, a large investment in improving water supplies for Perth and more conservative water management.

The seriousness of Perth's surface catchment inflow decline and its ongoing nature are demonstrated by the annual and average inflow amounts shown in **Figure 9**. From 1911 to 1974 annual inflow varied significantly, by a factor of 10, and average inflow was 338 gegalitres per annum. From 1975 to 1996 the variation in annual inflow fell to about 4, while average annual inflow was only 164 gegalitres. From 1997 to 2002 average inflow reduced further to 115 gegalitres. A further reduction in rainfall would reduce streamflows by a factor of three and possibly further reduce runoff by more than 30 per cent around the year 2050 (Betri *et al.* 2004). This trend has significant implications for water planning and highlights the need for an increasing focus on water management.

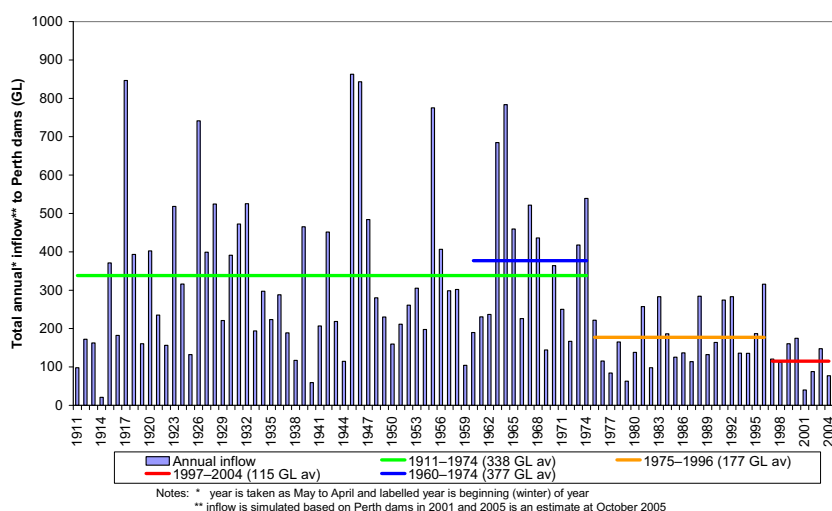


Figure 9 Annual inflow into Perth's dams.

Similar reductions in rainfall and surface water runoff have occurred throughout most of SWWA (see Figure 3, above).

As rainfall is the main contributor to coastal aquifer systems, declining rainfall is also a key contributor to reduced recharge to these systems. Lower rates of recharge for several years, changes in land use, and increased groundwater pumping have contributed to declining groundwater levels on the Gnangara Mound. However, reduced rainfall over the last 25 years is the primary cause of the decrease in stored water volume shown in **Figure 10**. From 1979 to 2004 the decrease in storage is equivalent to approximately two years of recharge. Even with the relatively small decline in total storage, approximately 0.1 per cent, impacts of groundwater declines are evident in SWWA's coastal lake systems. Despite conservative water management this represents a critical problem for the Perth water supply (Sadler, 2002 cited in Pittock, 2003, p. 50).

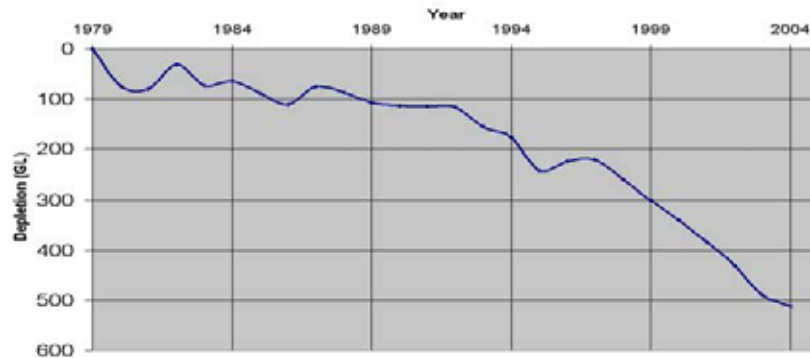


Figure 10 Groundwater Storage Depletion at the Gnangara Mound.

Responses to decreasing rainfall

The water sector responded to decreasing rainfall in four principle ways.

1. Shifting water harvesting from surface catchment to groundwater to desalination, using engineering and water resource knowledge.

In its earliest years, Perth relied on groundwater, but by the turn of the 20th century the first large water supply sources were from surface water fed dams built along the Darling Scarp. From about 1925 to 1975 Perth's water supply system relied primarily on surface water catchments, supplemented to a greater or lesser degree by groundwater as required by annual rainfall and surface inflow. The trend of reduced flows into Perth's public water supply surface reservoirs after about 1975 has generally shifted reliance for public supply from surface water to groundwater augmented by available surface water supplies and most recently by water from a desalination plant.

2. Increasing knowledge of underlying climate trends and drivers and recognising climate as a variable input to water resource decision-making.

In response to critical investment decisions about future water resources, the public water sector strongly supported the establishment of a climate research program focussed on climate variability and change in SWWA, the Indian Ocean Climate Initiative (IOCI) IOCI research has greatly improved awareness of climate impacts on water resources and has prompted a number of adaptive responses for managing the State's water resources. The Department of Water now uses a standard climate reference period of 1975 to 2003, among others, to evaluate proposed water source developments.

3. Managing demand

During the 1960s and early 1970s the State's water service provider, the Metropolitan Water Supply Sewerage and Drainage Board (MWSSDB), responded to high population growth and increasing per capita demand for water with continued development of surface water dams south of Perth and by initiating groundwater investigations. In the mid-1970s the Board recognised the importance of water use efficiency, introducing user pays pricing in 1978. This achieved sustained water saving as shown in **Figure 11**.

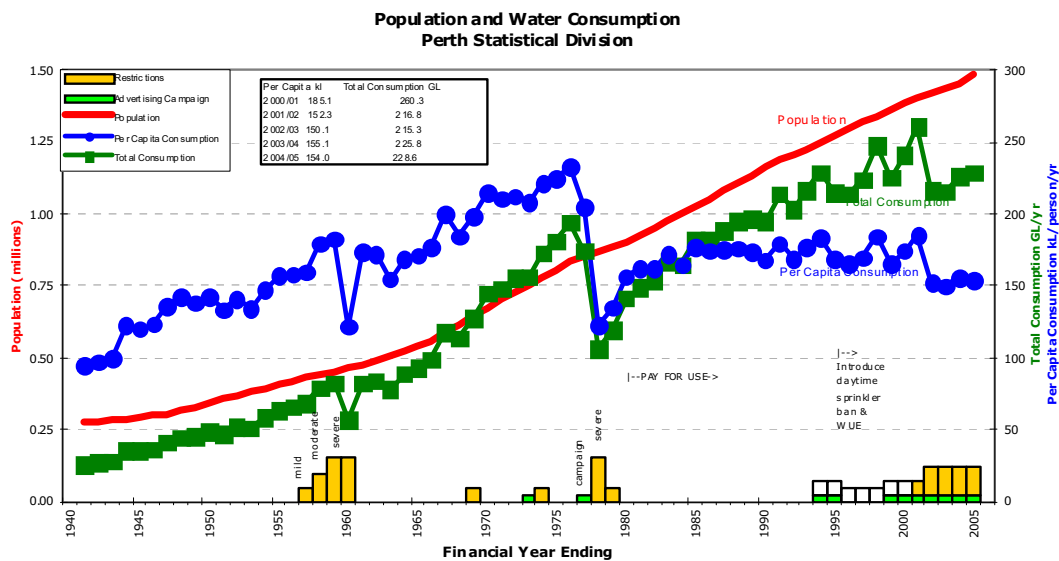


Figure 11 Historical per capita water demand for Perth.

4. Integrated water system planning

As reduced rainfall conditions continued from 1987 to 1995, the Western Australian Water Authority (now the Western Australian Water Corporation) made downward incremental adjustments to the water system's estimated yield. In 1995 the Government prepared *Perth's Water Future*, in which the Water Authority highlighted the potential future threat that climate change could have on source development options. *Perth's Water Future* identified that a new water supply strategy with additional sources and water use efficiency measures was needed to meet anticipated future demand for water.

A *Climate Variability and Water Resources Seminar and Workshop* was held in early 1996 to review current knowledge, and assess impacts on water supply for SWWA. The workshop recommended that Government water agencies review their position on climate change, climate variability and water source development.

In 1996, the decision was made to de-rate Perth's water supply system yield by 54 gegalitres, based on stream-flow data. The Water Corporation accelerated a detailed source development plan based on *Perth's Water Future* in an attempt to restore reliability to Perth's water supply. This included both groundwater and surface water sources, such as Harvey Dam and Yarragadee bores. Because of the higher dependency on groundwater, a pump station at Belmont was fast tracked to allow distribution of the extra groundwater. In addition, ongoing dry conditions resulted in a sustained education campaign to save water.

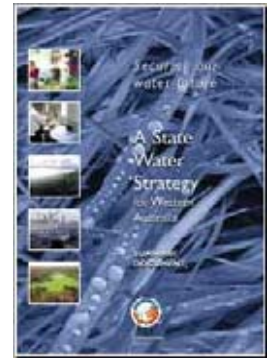
The winter of 2001 saw the lowest inflow to metropolitan dams since 1914, resulting in about 40 gegalitres of inflow to surface water storages. The 2001/2002 winter sequence represents the worst two-year drought on record, and forms part of an eight year sequence commencing in 1997, during which average streamflow (115 gegalitres per year) has been significantly lower than the post-1974 average of 161 gegalitres per year.

The Water Corporation's response included water use restrictions and further acceleration of the source development strategy. This saw the construction of nine superficial aquifer bores at Mirrabooka and two pipehead dams at Samson Brook and Wokalup Creek. Per capita demand was reduced to as low as 150 kilolitres a year.

The Government has implemented a number of other measures since 1995 to conserve the State's water resources. For example:

- the Department of Environment (which merged with the Department of Conservation and Land Management (CALM) on 1 July 2006 to become the Department of Environment and Conservation) has developed water efficiency and conservation plans with industry groups and local governments throughout the State;
- water licence conditions have been used to promote and regulate the efficient use of water;
- environmental conditions on groundwater impacts on the Gnangara and Jandakot groundwater mounds are reviewed annually by the Environmental Protection Authority; and
- environmental conditions are reviewed to reflect changing ecology and management needs under current climate trends.

In 2002, the *State Water Strategy* was developed to address key water issues and provide a platform from which solutions could be implemented. The strategy established a framework to improve water use and reuse where long term targets have been set to reduce per capita consumption to 155 kilolitres per person per year and to reuse 20 per cent of treated wastewater for the Integrated Water Supply Scheme. To help achieve these targets the State Government introduced incentive programs for using water efficient devices and the Water Corporation increased its efforts with the garden and plumbing industries, and with schools to promote waterwise organisations. Recent Water Corporation initiatives to increase water supply include the following new sources:



- A 45 gigalitres per year seawater desalinisation plant at Kwinana.
- A proposal to access the South West Yarragadee groundwater aquifer (45 gigalitres per year).
- A water trade agreement with Harvey Water (17 gigalitres per year).
- Catchment management (four to six gigalitres per year in the Wungong Catchment).

The State is also looking at more creative ideas for addressing the rainfall decline, with the Water Corporation investigating cloud seeding as an option to secure water supply. A \$100,000 project with the Bureau of Meteorology will look at the potential for cloud seeding to provide more rainfall from clouds into water supply catchments in the Darling Scarp (Titelius, 2006).

In planning for our water future, the Water Corporation has adopted a 'Security through Diversity' initiative that is now the corporation's strategic priority. This will see a broader range of new water sources developed to secure water supplies, even in times of drought. These new sources will be supported by a strong focus on reducing water consumption and becoming more efficient in the way water is used.

Private supply

As with public water supply, the reliability of private supplies has also decreased. The decrease in surface water flows in highly-used systems has seen an increased level of competition for water resulting in a greater number of stream disputes. Consequently water users have emphasised the need for a more clearly defined system of water entitlements.

Additionally, there has been an increasing focus on sustainability of surface and groundwater systems, beginning in the 1980s and intensifying in the late 1990s. This was in part recognition of the need to understand system behaviour under the added influence of climate change. As a result, understanding thresholds for vulnerable and threatened ecological communities and their relationship to climate change is now part of new major source development proposals and planning processes.

Recognition of the diminished water supplies has helped drive water use efficiency, particularly in the irrigation sector, and has also placed new emphasis on planning and policy development that clearly defines how water is shared. Access to a reduced level of water resources availability, partially caused by climate change, will continue to intensify competition between social, economic and environmental value systems and promote further debate on how adjustments are made.

The Department of Environment began processing small groundwater trades in fully allocated groundwater systems before 2005 but it was not a major factor at that time. Trading is expected to feature more prominently in the future, as evidenced by a large surface water trade between the Water Corporation and Harvey Water. Mechanisms to improve water trading are currently being progressed by the Department of Water through programs linked to Government's response to the Western Australian Irrigation Review and the National Water Initiative.

The recent reinstatement of the State Groundwater Investigation Program is another important step to improve the capacity to manage groundwater resources sustainably. A \$28 million investigation and monitoring program is planned for the next 15 years to provide:

- a better understanding of the distribution and quality of the State's water resources;
- information to support, encourage and enhance sustainable water use in mining, industrial, agricultural and regional development; and
- new data to guide water resource management under variable climate conditions.

Rural water supplies

Recurrent and often serious water supply problems in dryland agricultural regions between the 1960s and early 1990s led to the development of a Rural Water Plan in 1995. The plan is administered through the Department of Water and consists of a number of key program initiatives designed to:

- encourage on-farm water supply self sufficiency;
- improve the reliability and quality of on-farm water supply; and
- provide rural communities with reliable emergency water supply arrangements.

Since 1995 successive State Governments have remained committed to ongoing implementation of the plan, to the extent that more than \$100 million has been invested to improve on-farm and community water supplies. State Government investment of approximately \$50 million has been provided through grants matched with similar contribution from landholders and rural communities. An additional \$25 million in capital funding has been provided by the Water Corporation for new and extended piped water services to rural towns and adjacent farmlands.

While these investments have resulted in significant improvements in farmland and pastoral water supplies there remain areas that continue to be susceptible to serious water deficiency. More effective and efficient catchment water management, including improved water harvesting technology will be required to meet water demands in the face of climate change, land and water degradation, and increasing pressures for environmental flows.

During the past 30 years, farmers have shown considerable ingenuity in developing crop management practices to use water efficiently and water harvesting techniques to improve on-farm water supplies. New crops and crop varieties have been introduced that offer increased profitability in the new climate conditions. As a result agriculture has remained reasonably profitable in the face of declining water supplies during the past 30 years or even increased profitability where waterlogging frequency has decreased. However there was broad agreement among farmers at the consultation sessions that the agricultural sector must continue to improve water use efficiency.

The future

Ongoing uncertainty about SWWA's future climate threatens the security of the State's traditional surface and ground water resources. The Department of Water and supporting agencies will seek to manage this uncertainty through integrated water resources planning, management of use and water resources assessment, informed by the best climate, environmental and social research. A new legislative framework is to be introduced to better accommodate the challenging future for water resource management.

The water sector has responsibility for making decisions about the long term, sustainable management of water supply. The fact that almost all other sectors are heavily reliant on water in one way or another highlights the importance of integrated planning and the need to account for the vulnerabilities and potential conflicts that are experienced between sectors. Well-developed working relationships between water utilities, water users, water resources managers and environmental regulators, as well as communities, are essential to enable planning and development in response to challenges posed by a drier and warmer climate.

Conclusions

Reduced rainfall from the 1970s presented the water resources sector with significant but relatively clear challenges. While the precise nature of the change in climate itself was not fully apparent for about 20 years and the atmospheric forces which created it are yet unknown, the non-linear (magnified) impacts of reduced rainfall on surface water runoff established early on some well-defined challenges for water resource and supply managers, the community and industry.

Through a combination of source diversification, improved understanding of climate and integrated planning including demand management, Perth and other parts of SWWA continue to enjoy sufficient quantities of high quality water to support the region's lifestyle, industries and communities. As the region's population continues to increase, further measures will be required, particularly if rainfall continues to decrease.



NATURAL ECOSYSTEMS AND BIODIVERSITY

The role of climate in natural ecosystems



Climate is a fundamental determinant of the species found in a location and of the ecological processes that develop there. Other major determinants include the availability of nutrients, soil type and surface geology (for terrestrial species), water

quality (for terrestrial, aquatic and marine species), competition between species, natural forces such as fire or storms, predation and chance. Because many factors affect the presence and health of ecosystems and species, the role of climate is often difficult to determine. However, it is clear that an enduring change in climate will result in a similarly enduring change to ecological systems.

Instances in which there are clear and direct associations between a change in climate-related environmental conditions and a change in species presence, phenology, health and ecosystem structure and functioning are rare where climate conditions demonstrate high variability, such as in Australia. However, in some instances where a climate or weather variable is well recorded and a threshold is understood to exist, the direct impacts of climate can be observed and reported. Coral death and bleaching are caused by ambient ocean temperatures higher than certain limits. In addition, there is increasing evidence of changes in phenology that are consistent with theoretically logical functional responses to observed climate change.

The emerging need to manage the effects of climate change highlights both the need to determine the role of climate and the difficulty in doing so in many instances.

Managing complex, self-adapting ecological systems

Management of Western Australia's ecological systems and biodiversity values involves:

- protecting areas through reservation (e.g. nature reserves, national parks, conservation parks, marine parks);
- protecting landscapes, ecosystems and species and individual plants and animals from threats such as fire, disease (e.g. *Phytophthora cinnamomi*) and poisons (e.g. salt) through firebreaks and active on-ground management;
- enabling public use and enjoyment of natural areas through facility planning, development and management (e.g. roads, campgrounds, information);
- introducing species with a limited distribution to other areas through translocation (e.g. Gilbert's potoroo); and
- protecting very rare and endangered species through germplasm libraries.

Biodiversity management in Western Australia is based on science: primarily biology, ecology and soil science, augmented with mathematical and statistical analysis. Climate and weather are essential elements of this science and are necessary inputs for most management activities, including designing the State's reserve system, fire and disease management, and facility development.

Sectoral response to climate change

For many years, until the late 1980s, climate was treated as a factor that was highly variable but stable within wide boundaries. The management of fire provides an example of this approach.

Departmental Annual Reports for the 1970–1988 period, which contain brief summaries of the year's weather conditions and of key weather data in conjunction with a description of fire management activities for that year, indicate a persistent practice of describing what is now understood to be a change in the climate of the south west as an ongoing series of unusually long and dry summers.

Summers were described as predominantly drier than normal (1972, 1973, 1975, 1977, 1978), longer than normal (1975, 1976, 1977, 1978), hotter than normal (1975, 1978) or having an extended fire season (1979). After an 'average' year in 1980, the following years are reported as having:

- a prolonged fire season due to late commencement of autumn rains (1981);
- extended stable autumn weather (1982);
- generally warm and dry weather with an extended autumn (1983);
- longer than normal fire season due to an extension of dry conditions in April (1984);
- longer than normal fire season due to an extension of dry autumn conditions until late May (1985);
- average fire season (1986);
- extended dry conditions in autumn (1987); and
- extremely dry weather conditions from early spring to late autumn and one of the longest fire seasons on record (1988).

The lack of awareness of climate change seems surprising from the present perspective but before 1987 land managers had limited professional incentive to consider this factor. There was little broadly-circulated Australian scientific research on climate change before then and the matter was virtually untouched by Australian policy development. By contrast, SWWA had long been celebrated as having a relatively predictable climate in comparison with other parts of Australia.

Climate change was finally highlighted in the 1989 CALM Annual Report, in which it was identified as a significant concern. A newly-established internal greenhouse policy committee and CALM's participation in the State's Greenhouse Interdepartmental Committee was announced. In the 1990 Annual Report, however, the main specific threats to biodiversity were listed as grazing, predation, fire, weeds, competition, fragmentation, vehicular use, clearing and dieback, with no reference to a threat from climate change. While the potential impacts of climate change on Western Australia's biological systems were considered to be significant, this issue was felt to be more remote and less certain and urgent than the other threats.

Interpretation

Higher awareness in the late 1980s that SWWA might be experiencing an enduring climate change probably resulted from the CSIRO sponsored Greenhouse 1987 Conference, contemporaneous international meetings in Toronto and Europe, and establishment of the IPCC.

The direct experience of changed climatic conditions in SWWA during the period 1972 to 1989 was probably another key factor which resulted in climate change being perceived in 1989 as directly and immediately relevant to Western Australia. Increased international and national climate research and policy analysis supported considerations by scientists and land managers of the nature of climate change implications for Western Australian biodiversity. A key factor was probably the choice by CSIRO to highlight at the Greenhouse 1987 Conference those climate changes already known to have occurred in the region and to project major rainfall declines for SWWA in the conference scenario.

The omission in 1990 of climate change from the list of key threats to biodiversity was a pragmatic response to a problem of global dimensions. The key characteristic differentiating the threats listed in the 1990 Annual Report from climate change (and from salinity, which is also not listed) was that those listed could be addressed within the bounds of CALM-managed lands, or relate directly to its management actions. In other words, the threats listed in 1990 are those against which CALM could realistically take effective action, even if some, such as dieback, were, and remain, daunting.

During much of the 1990s CALM (the department then responsible for managing and protecting biodiversity) focused its research and management efforts on the threats listed in its 1990 annual report. However, CALM also became a leading Australian advocate of carbon sequestration to reduce global atmospheric carbon dioxide concentrations and to support revegetation for protecting and enhancing biodiversity values. This option was very important to Australia, Western Australia and some other States as Australian fossil fuel exports increased and the need for revegetation simultaneously became ever more apparent. From the first Australian Greenhouse Response Strategy in 1992 to 2004, Australia's national climate change policy has focused mainly on reducing Australia's net gas emissions, and this focus has been reflected in most States, including Western Australia.

Current situation

While the initial emphases on revegetation, carbon sequestration and related biodiversity and ecological benefits remain key objectives for biodiversity management and climate change response in Western Australia, there is now also greater emphasis on understanding and managing the risks to biodiversity associated with unavoidable climate change. Climate change considerations are now a standard aspect of land management plans for national parks and nature reserves, and form an important element in research programs. The extent of achievement and remaining requirements in this regard are summarised in the status report of the National Climate Change Biodiversity Action Plan 2004-2007. The effectiveness of these responses will take some time to determine, but a shift towards greater climate change impact mitigation is evident since 2000 as IOCI clarifies the nature of the climate changes which have already affected SWWA's ecological systems.

A typical regional example is a project on the South Coast aimed at trialling the feasibility of incorporating climate change into regional recovery and threat abatement planning, part of a broader project looking at recovery and threat abatement actions for all threatened species and ecological communities. Its objectives are:

- to explore opportunities for the regional recovery and threat abatement plan to account for climate change impacts on threatened species; and
- to the extent possible, modify actions and management to assist threatened species to adapt to climate change.

Early findings from the project suggest that, based on current knowledge, the resilience of species to climate change should be increased by:

- maintaining existing large reserves and increasing the connectivity of natural landscapes across Australia;
- the identification and focused management of areas particularly vulnerable to climate change; and
- the continued management of other threatening processes that may be exacerbated by climate change (e.g. fire and *Phytophthora*), with an increased focus on species or areas, which may also be particularly vulnerable to climate change.

The findings also suggest that further research is needed on:

- the biological and ecological response of species to climate change in order to determine their vulnerability; and
- the impact of climate change on other key threatening processes in the region (e.g. fire).

The approach taken by this project exemplifies the complexity of integrating climate change into ecological management, the limited tools available and the extent of the uncertainty underlying management decisions.

AGRICULTURE

Introduction

Agriculture has been a major economic sector in Western Australia since European settlement and a major export industry. However, Western Australian agricultural practices and products have changed in response to many forces, including demand, competition, market availability, technology and innovation. In less than 50 years, from 1960 to the present, agriculture has changed from an industry which operated on many relatively small holdings producing a limited range of commodities, most of which were sold in bulk for export, to a technically advanced industry producing a highly diverse range of niche products, some of which are exported in bulk but many of which are transformed to highly valuable products.



Modern farming requires knowledge of finance, economics, chemistry, biology, genetics, information technology, record keeping, and resource management. Managing climate variability is also an inherent part of running a farming enterprise from one year to the next. Consequently, successful Western Australian farmers must be able to manage the risks associated with short term, seasonal and intra-seasonal climate variability. However, it is now understood that farmers must also understand and respond to longer-scale climate changes where these occur if they are to remain profitable over decades and generations. The inevitable focus on managing short-term variability appears to have effectively masked the agricultural sector's longer-term, more gradual adaptation responses to the observed climate changes that have affected SWWA during the past 30 years.

In retrospect, several significant actions taken in the period since the 1970s were in effect adaptations to longer-term climate changes, such as actions to ensure the security of on-farm water supplies. Recurrent farm water supply shortages since the 1970s drove requirements for integrated farm water planning, which was essentially tacit acknowledgement of lower rainfall. But this was masked by more immediate needs and pressures including addressing floods and soil erosion in the 1960s, drought in the 1970s, and soil erosion and sandblasting from wind in the 1980s. These pressures took precedence over longer-term considerations about changing weather patterns, and the impact this might be having. This persisted into the 1990s when farmers were focused on increasing international competitiveness in a State where 80 per cent of agricultural products are exported and food security is not an issue.

In more recent times climate change has emerged as a major issue for agriculture, and it has been factored into the Department of Agriculture and Food, Western Australia's (DAFWA's) strategic planning since 2003 following:

- three consecutive years of drought declaration;
- increased confidence in the findings of climate research;
- ongoing stress on water supplies; and
- the launch of the Western Australian Greenhouse Strategy.

Agricultural research and development organisations are increasing their focus on climate change impacts. The Grains Research and Development Corporation (GRDC) has focused on climate variability since 1992 under the Climate Variability in Agriculture Program, which was replaced by the Managing Climate Variability Program in 2003. This is a partnership of Research and Development Corporations providing funds for research and extension to help farmers improve climate risk management.

Adaptation is essential to reduce the vulnerability of agriculture to the impacts of climate change. A range of adaptive measures have been used to overcome the adverse effects of climate change on agriculture. At a farm level these include:

- the introduction of earlier-maturing crop varieties;
- switching cropping sequences;
- sowing earlier and faster, and adjusting timing of field operations; conserving soil moisture through tillage methods; and
- in irrigated areas, improving irrigation efficiency or shifting out of low profit enterprises.

Some options, such as switching crop varieties, can be inexpensive but others, such as upgrading irrigation systems, involve major capital investments. Adaptation therefore can result in significant 'residual' vulnerability for farm businesses. Where a significant shift in land use is required from, for example, cropping to extensive grazing based on perennials, farmers may find themselves more exposed to marketing problems and cash flow crises due to high transitional costs and reduced profit margins.

Environmental risks are also likely to be exacerbated by climate change, which could result in policy responses that further complicate adaptation. This highlights the need for integrated responses and incorporation of local knowledge into decision making.

Major changes in agricultural practices and production: 1960 to present

A historical review of agriculture from 1960 to the present focusing on climatic events and responses reveals how the sector and its profitability are inherently affected by climate, and how climate drives decision-making. In particular it demonstrates how changing weather is a significant factor in driving adoption of new technology and focusing research and development efforts.

The 1960s—from floods to drought



Extensive flooding occurred in agricultural areas during 1964, which was one of the wettest years on record. Fruit trees and vines were lost in horticultural districts, flooding damage occurred in heavily forested catchments and resultant widespread soil erosion led to requests from farmers and farmer groups for advice about controlling surface water and salt land management. For example, 683 properties (67 560 acres) were surveyed for contouring and drainage.

In 1965, above average rains in the wheatbelt and favourable seeding conditions led to record yields, but erosion control was again a major issue accentuated by the previous year's floods. In response the (then) Department of Agriculture stationed soil

conservation officers at Geraldton, Moora, Northam, Narrogin and Katanning to provide specialist erosion control design and advisory services.

The 1967 season commenced with a very late start for lower west coastal areas. This was followed by an early finish to the growing season and an exceptionally early and dry summer. As a result horticulture and dairy production experienced problems, although wheat production was above average.

In 1969 rainfall was well below average and most districts had their worst season for many years. By the end of August 1969, 18 shires were declared drought affected by the State government. Districts such as Harvey and Manjimup received 685 mm compared with their annual average of about 1100 mm.

The 1970s—water conservation

The demand for assistance with water conservation, irrigation and drainage increased during 1969 and 1970. Private irrigation schemes were developed from Gingin in the north to Busselton, Margaret River, Donnybrook and Manjimup in the south. All districts were affected by the low 1969 winter rainfall and ongoing drought for the remainder of the year. Southern agricultural areas, particularly to the north and east of Albany, suffered stock water restrictions, and invested in on-farm water conservation. In fruit-growing districts, the interest in orchard irrigation schemes continued while in several districts there was increased demand for drainage advice from farmers able to carry out work in areas normally too wet for operating earthmoving equipment. In response the Department of Agriculture stationed an adviser at Manjimup in January 1970 to advise farmers and orchardists on water conservation, irrigation management, drainage, and soil conservation.

The 1971 season for wheat cropping started promisingly with heavy rains in March but follow-up rains were disappointing. In 1972 the growing season broke late and finished early and crops were poor in many major wheat growing districts. Again in 1973 opening rains for the main cereal growing areas were below average leading to slow pasture growth and feed shortage. As a result of three years of below average rainfall, on-farm water supplies for both stock and irrigation were seriously depleted and salinity levels were increasing.

Below average rains for most of SWWA in April, May and June 1976 produced the longest dry spell in 16 years, causing feed shortages for livestock in the wheatbelt. Farmers began selling stock in June due to poor pasture growth and lack of on-farm grain supplies. Following the very dry opening to the 1976 season, rainfall continued to be below average. Wheat production fell by 21 per cent despite an increase of nearly four per cent in the area planted, and lupin production fell by 75 per cent. Sheep and lamb numbers fell by 10 per cent while beef cattle numbers fell by five percent.

Furthermore, there was insufficient run-off to fill the main irrigation water storages of Government controlled schemes. Irrigators supplied by the Wellington, Harvey and Waroona storages were warned before the start of the season that they would be rationed well below their normal water usage. The scheme of 'Planning by Order' allowed farmers to schedule their water more accurately, greatly assisting management of pastures with the limited supplies.

Compounded by poor markets for beef and dairy products and severe hail damage to much of the State's apple crop, the 1976 drought conditions reduced many farm incomes. State aid to drought affected farmers was implemented in late July with a plan involving:

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- carry-on loans in emergency cases for buying stock feed;
 - rail and road subsidies for carting feed or livestock for agistment,
 - arrangements with the Australian Wheat Board (AWB) for release of feed grain from country storages; and
 - financial contributions from the Australian Government towards carry-on loans, subsidies for agistment and cost of feed grain from the AWB. Unemployment benefits were also provided to farmers who received no income or very low income due to the drought.

By early 1977 the Government had spent \$1.25 million on drought aid and granted an additional \$515 000 for unemployment relief.

Light but sufficient rainfall opened the 1977 season, but unfortunately this was followed by little more than half the average June rainfall, prolonging the 1976 drought in some areas. Further damage to the State's agriculture came in February 1978 when hail, wind and flood damage in the lower south-west, and heavy rain and flooding in the eastern wheatbelt, affected about 300 farmers. By early March 1978 the area of the State affected by drought was greater than in 1977. In April 1978 Cyclone Alby severely affected apple and vegetable crops and added to the woes of sheep exporters. Government aid specifically associated with the cyclone went to 195 farmers. These two years of drought and extreme events had a serious impact on Government funds and on the State's major agricultural enterprises of sheep and wheat.

Western Australia's rural economy generally improved during 1979 with an increase of \$450 million (total value of \$1430 million) in the State's gross value of rural production. However, dry conditions continued for the third successive year for some farmers in Northam, Mullewa, Morawa, Mingenew, Perenjori, Dalwallinu, Mount Marshall and Yilgarn. Government assistance was again made available to 169 farmers in the forms of loans, subsidies for transporting stock to or from agistment and for transporting fodder.

Despite the climate adversity faced by the agricultural industries throughout the very late 1960s and the 1970s, an assessment of records related to the sector during this time does not reflect any real acknowledgment yet of climate change as Australia was known for large-scale climate variability. Some 30 years later however, this period could be identified as the initiation of an abrupt reduction in winter rainfall and delayed opening of the growing season.

The 1980s—wind, sand and technology

Winter rains failed in many agricultural areas in 1980 and for some farmers it was the fifth consecutive year of drought. Satellite (LANDSAT) imagery recorded on August 16 1980 indicated that about 44,000 ha of cropped area in the central south coast was severely eroded as a result of low rainfall, causing total crop failure in this area.¹

Cultivation contributes to erosion, especially of sandy-surfaced soils. A Department of Agriculture survey found that farmers in the affected area understood that more cultivation resulted in looser soil and greater vulnerability to erosion. There was universal interest in minimising the number of times a paddock was worked.



¹ The 1980s saw a number of changes in farming practices and technology applied to improving resource management, particularly soil resources.

The start to the 1981 growing season was similar to 1980, with cold, dry and windy conditions in May and June leading to widespread sand blasting of pastures destroying clover establishment and reducing surface organic matter in many areas. Pastures partly recovered, but areas sown to cereals were slow to establish ground cover because of cold windy conditions and sand blasting.

At Esperance, about 20 per cent of paddocks drifted badly with sand piling up on fence lines and roadways. These events highlighted the fragile nature of the south coast's light soils and renewed farmer interest in soil conservation. Soil management strategies included perennial pastures, cropping with minimum cultivation, tree shelter belts, reducing stocking rates and contour farming.

By 1982 significant changes were taking place in Western Australian agriculture. Research into land degradation was significantly increased, with renewed emphasis on farming systems research aimed at:

- minimising soil disturbance and maximising rainfall infiltration and usage;
- reducing input costs and energy requirements through reduced tillage;
- controlling diseases favoured by low tillage regimes; and
- weed control through the use of selective herbicides.

A major extension effort was undertaken to help farmers benefit from improved technology and crop varieties that emphasised seeding as early as possible and maximising water use. The introduction of lupins provided farmers with a viable alternative to pasture as a disease break and fertility improver phase of a cropping system better suited to increasingly dry conditions.

During 1983 favourable weather conditions enabled Western Australian farmers to produce more than seven million tonnes of grain, including almost six million tonnes of wheat. This success can be attributed to a number of improved management practices arising from research introduced to farmers in preceding years. Farmers sowed almost two million ha of crop using minimum and reduced tillage techniques demonstrating their continued confidence in the technology; for example by spending more than \$36 million on herbicides. These techniques provided effective weed control, reduced risk of soil erosion and improved soil structure on many heavier soils, and there were direct yield increases as a result of earlier seeding. In addition, lupin cropping became prominent as part of rotations with cereals in drier parts of wheatbelt.

During the 1980s, the agricultural sector addressed problems with soil erosion and soil moisture availability by minimising soil tillage and disturbance. While this practice reduced planting and weed management costs, it also enabled cropping to continue under significantly drier conditions. This change was primarily introduced to effectively address climate change impacts at a time when climate change per se was still unacknowledged by the great majority of farmers and agricultural scientists.

The 1990s—a profitable decade

The key objective of the Department of Agriculture in the 1990s was to increase international competitiveness by reducing costs per unit output, with natural resources management remaining a core priority. During this decade the Department of Agriculture's reporting did not generally highlight issues associated with climate variability or climate change, probably because there were few especially dry years and minimum till and other water conserving practices had been broadly adopted.

It was noticeable however during the 1990s that cropping in the so-called woolbelt areas increasing markedly, driven by low wool prices, relatively low rainfall and improved production packages. Traditionally winter waterlogging was a high risk in the woolbelt but the drying trend had tipped the balance in favour of cropping.

The Department of Agriculture undertook work with farmers to assist them in managing seasonal variability. In 1992 a decision tool called TACT was developed to allow farmers and advisers to make best-bet decisions about how the amount of area cropped should change in response to varying seasonal conditions. It provided probability of different wheat yield outcomes and the probability of different gross margin outcomes given rainfall up to seeding time. In addition, MUDAS (Modelling of an Uncertain Dryland Agricultural System), a whole farm model was also developed, which incorporated both commodity prices and seasonal variation into calculations. These were all part of the 'toolkit' for enabling farmers and their advisers to manage the risks from low and/or delayed winter rainfall. Generally at this time climate variability rather than climate change was the preferred language even though scientific evidence was mounting that climate change was now a management factor.

During the 1990s the extent and duration of rainfall reduction resulted in climate change becoming a common perception in much of SWWA's agricultural community, complicating an already challenging list of management issues: globalisation, shifting product demand, climate variability, interest rates, salinity, weeds and others. Greater knowledge about prospective future climate regimes, and greater capacity to use this knowledge, became priorities.

Climate change adaptation in agriculture— a case study of wheat growing

Wheat cropping in Western Australia has undergone significant change during the past 40 years through new technologies, management practices and regimes. It has also continued to return considerable profits to the State and its farmers, despite the impacts of declining terms of trade, land degradation and declining winter rainfall. The average rate of yield increase from 1950 to 1990 was about 12 kg per ha per year, rising sharply in the 1990s to about 55 kg per ha per year.



In the 1960s bare fallowing was the basic technique for cereal production, whereby paddocks were ploughed in July or August and kept bare for nine or 10 months. This method improved weed control and seed bed preparation, increased moisture storage for crop use, enhanced plant nutrient availability, improved insect pests and diseases control, and reduced seeding time once land preparation was finalised. The overall effect was claimed to be a 30 to 40 per cent increase in wheat yields. However increasing mechanisation, the introduction of leguminous pastures, and chemical weed and pest control has reduced its benefits. Erosion and increasing grazing requirements also reduced the apparent benefits of bare fallowing and consequently the practice was not generally recommended after the mid 1950s.

Low wool prices, wheat quotas and other factors in the early 1970s created an environment in which reliable crop returns appeared more important than maintaining maximum acreage under pasture. A trial program to assess fallowing as a management option began with a study of soil moisture accumulation under various fallow and non-fallow treatments at Merredin Research Station. Yields in 1973 and 1975 were greater with fallow than non-fallow, with results generally demonstrating higher yields from increased moisture supply, either through fallowing or higher rainfall.

Yield increases continued and by 1980 cropping patterns started using the first chemical fallow in the central wheatbelt. New crop varieties, changed management practices and improved water use efficiency led to higher yields even during lower rainfall seasons. Yield increases have accelerated since the late 1980s, despite several drought years and widespread frost losses. Wheat yield trends together with management changes that contributed to increases in wheat yield are presented below in **Figure 12**.

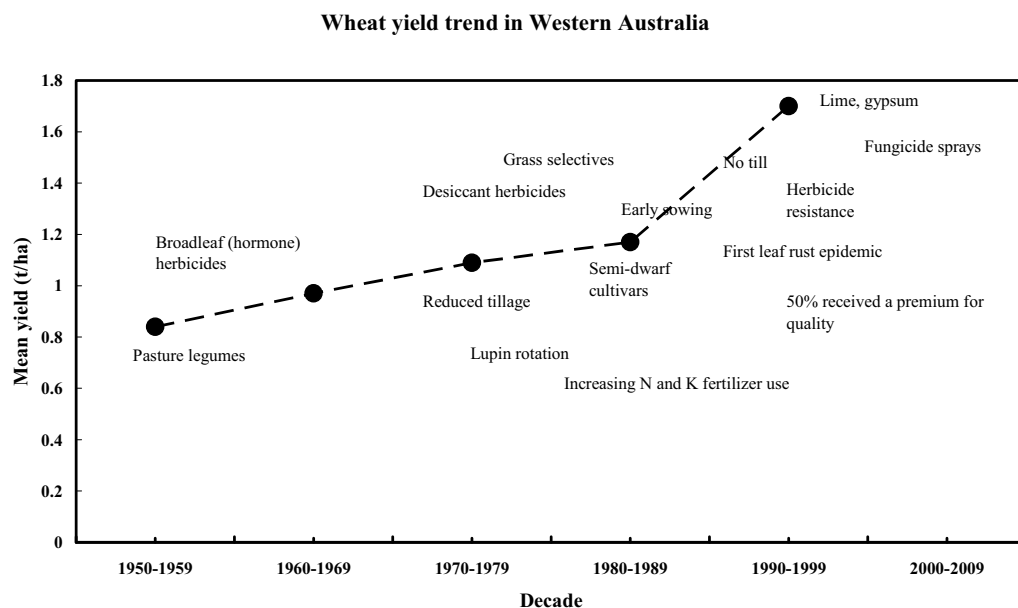


Figure 12 Wheat yield trend for Western Australia, 1950 to 2007.

Source: Anderson, WK *et al.* 2005. The role of management in yield improvement of the wheat crop—a review with special emphasis on Western Australia, *Australian Journal of Agricultural Research* 56(11): 1137–1149.

Reduced tillage and early sowing can now be identified as the two most significant agricultural innovations arising from reduced rainfall. Early sowing which began in the 1980s had not been used prior to this time due to problems with weed control and risk of erosion from bare cultivation. However, the use of desiccant chemicals before sowing enabled crops to be sown without the need for extensive tillage. As a result the average sowing time for wheat in Western Australia moved forward by about three weeks in the late 1980s and early 1990s.

In summary, while climate change has reduced rainfall in most parts of the WA wheatbelt, “yields from rain-fed wheat crops in Western Australia have doubled since the late 1980s and water use efficiency has also doubled. The percentage of the crop in Western Australia that qualifies for premium payments for quality has increased three to four fold since 1990. Both these trends have been underpinned by the gradual elimination or management of the factors that have been identified as limiting grain yield, grain quality or long term viability of the cropping system” (Anderson *et al.* 2005).

Sharper focus on climate since the late 1990s

Industry impacts

The late 1990s and the 2000 growing season were particularly difficult for the agricultural sector, being an extended period of below-average rainfall. This brought climate change into much sharper focus for the sector, and the Department of Agriculture invested in IOCI to better understand climate science and the Indian Ocean's influence on SWWA's climate. Record low rainfall was compounded by widespread frosts and a major outbreak of Australian Plague Locust (APL) in 2000 and 2001. Incidentally, another major outbreak of APL was anticipated in 2006 on the back of high summer rainfall and there appears to be a link between APL numbers and summer rainfall.

At this time the State Government made application to the Australian Government for Exceptional Circumstances assistance on the basis of exceptional drought, exacerbated by severe frost in successive seasons. The affected area included about 680 farms, including all of Lake Grace and parts of Kulin, Dumbleyung, Kent, Gnowangerup, Jerramungup and Ravensthorpe shires. The poor growing conditions continued into the 2001 season and the Department of Agriculture again prepared applications for Exceptional Circumstances assistance. However, while the extended drought conditions had a severe impact on some farms, other parts of the State experienced good harvests, particularly those where yields are often constrained by waterlogging under average rainfall conditions.

The dry conditions continued for some farmers into 2002 and 2003, providing a very challenging environment for agriculture as it faced its worst drought in more than a century. In response the Department of Agriculture conducted research on season analogues to improve forecasts of seasonal outlook, and advise on a range of tactical options for farmers to better manage climate risk in their businesses.

After a productivity decline in 2002/03, Western Australia's agricultural productivity recovered sharply in 2003/04. In fact overall output growth for the State's agriculture has exceeded Australia's for most of the past 15 years, but it widened significantly in 2003/2004 as several other parts of Australia continued to experience difficult seasonal conditions.

Western Australian Greenhouse Strategy

The Western Australian Greenhouse Strategy (2004) raised the priority of greenhouse issues and committed departments, including DAFWA, to a range of actions aimed at reducing emissions and adapting to climate change. DAFWA appointed a greenhouse coordinator and initiated a range of new activities including measuring nitrous oxide (N₂O) emissions from wheat, reallocating funds to seasonal variability forecasting and climate risk management, land use impacts, assessing sequestration potential, whole farm modelling of yield and financial impacts and adaptation options, and modelling the financial implications of changing to a new land use as a result of climate change. This work has been maintained through partnerships with various research funders, the crises arising from extended periods of drought in parts of the wheatbelt and the increasing weight of evidence and publicity about climate change.



Agronomic research

Further climate adaptations available to agriculture include breeding heat and drought-resistant crop varieties drawing on international germplasm banks, which can be screened to find sources' tolerances to heat and water stress and better compatibility with new agricultural technologies. Genetic manipulation may also help to exploit the beneficial effects of CO₂ enhancement on crop growth and water use.

DAFWA proposes to develop a Centre for Abiotic Stresses where resistance of wheat and barley to a wide range of abiotic stresses will be characterised and genetically enhanced as primary germplasm for breeding programs throughout Australia. The work of the proposed centre will potentially address climate change scenarios relating to increasing temperature and declining growing season rainfall throughout Australia.

Biosecurity

Biosecurity risks are expected to increase or alter under a changed climate regime. The World Trade Organisation requires all phytosanitary regulations to be based on risk assessment and various national and international schemes for pest risk analysis (PRA) are now under development. The assessment of climatic suitability based on climatic data is a key element in PRA. Although these data are critical for determining the likelihood of establishment, the economic damage caused by a pest introduction to a new area will depend on the degree to which the organism can thrive and spread over time. Future climate change should be considered in evaluating a pest's long term economic impact. To date, little if any modelling using CLIMEX has considered climate change scenarios. However, this is now being seen as an increased priority as a result of national dialogue and strategy development.

Reducing climate change impacts

Some observers believe climate change will exert its influence on agriculture so slowly—a fraction of a degree per decade—that the effects will be barely noticeable in the midst of other technological and economic changes. Others emphasise the need to study the potential for what are called 'threshold effects', which are abrupt and disproportionate shifts in production that may be triggered when critical levels of certain factors are surpassed. Even if the climate changes gradually, it will slowly affect the range of options available for agriculture in any given region, not to mention the unexpected consequences that may accompany accumulation of greenhouse gases. Under changing climate conditions, farmers' past experience will be a less reliable predictor of what is to come. These and other uncertainties must be taken into account in climate change policy formulation.

As well as gradual changes, extreme meteorological events, such as periods of high temperature, heavy storms and droughts will disrupt crop production. Where certain varieties of crops are grown near their limits of tolerance such extreme events can be particularly detrimental. Recent Department of Agriculture and Food studies have considered possible changes in the variability as well as in the mean values of climatic variables.

Some effects, such as river flooding or crop loss come into play only after certain limiting conditions or thresholds have been crossed. Identifying thresholds involves analysing the effects of different levels of climate forcing on an agro-ecosystem to identify the critical conditions under which the response of crops will abruptly change. These critical levels can involve either natural or socioeconomic factors, and both should be considered. For example, in the biophysical domain threshold temperatures have been defined for many specific crop processes and these need to be matched with future climate predictions and monitored to assess when risks become too high and action is needed.

An even more challenging task is to estimate the probability of coincidental events that might happen in conjunction with global warming, spanning the range between low probability catastrophic events (called 'surprises') and higher probability gradual changes in climate and associated environmental effects. A seemingly small change in one variable, such as rainfall may trigger a major unexpected change in another; for example, floods might disrupt the transport of grain or threaten storage infra-structure. Moreover, as biophysical and social systems are interconnected, one 'surprise' may then lead to another in a cascade. Computer-aided studies based on what are called *complex systems* and *chaos theory* may provide conceptual and analytical tools for anticipating and preparing for surprises in agricultural systems.

Conclusion and future needs

A historical review of SWWA's agriculture sector highlights a number of extreme weather events that took place. The extent to which these events reflect climate change as compared to climate variability is difficult to estimate. However, a number of events and responses do exhibit characteristics similar to those that could be expected under climate change, including:

- extensive flooding during 1963/1964 causing widespread soil erosion;
- the decision in 1969/1970 to station an adviser at Manjimup to increase farm advisory services for water conservation, irrigation management and drainage;
- implementation between 1975 and 1980 by the Water Authority of 'Planning by Order' to assist in managing irrigation pastures with significantly reduced water supplies. In addition, State financial aid was arranged for drought-affected farmers;
- the 1980/1981 introduction of imagery of LANDSAT to identify and overcome problems associated with sand blasting as dry seasons began to reduce pasture cover and increase the risk of poor crop establishment;
- the 1982 release of semi-dwarf crop varieties by the Department of Agriculture which gave outstanding performance on an extensive scale;
- the introduction of TACT, MUDAS and other models in the 1990s, which greatly assisted farmers and consultants improve farm planning by incorporating seasonal variability risks into decision-making;
- the provision of a Departmental Dry Season Taskforce between 2000 and 2006 to provide technical assistance to farmers on optimum management of crops, pastures and livestock in addition to EC based drought aid for the first time in WA; and
- following the release of the Western Australian Greenhouse Strategy, the adoption of research activities by the Department of Agriculture and Food in emissions, climate change and seasonal variability forecasting, land use impacts, revegetation and sequestration, modelling of yield impacts and adaptation.

In the past 30 years, technological change has increased the productivity and efficiency of Western Australian agriculture (see Figure 12) and enabled it to cope with the warming and drying trend in the climate over this period. There is optimism that this can continue, but modelling utilising projected climate change parameters, albeit uncertain, casts doubt over the viability of this response. It is likely that some adjustment to land use will be needed in some areas in response to long term climate change and this will threaten considerable private and public assets. Decisions about future investment in infrastructure and development will need to consider climate change impacts and lead to some painful social and economic adjustment. The Western Australian Government is now moving to fund a program to carry out vulnerability assessments and provide a framework for carrying out responses.

FORESTRY

Plantations and farm forestry represent significant land uses in parts of SWWA, with climate variability and change being major considerations in managing the existing resource and future expansion plans. Impacts of climate change on natural forests are considered in the section dealing with biodiversity.

Development work on carbon sinks is a direct response to changes in international climate change policy, particularly the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC).

SWWA's plantation estate

By 1990 approximately 100 000 ha of tree plantations² had been established in SWWA. These comprised mainly *Pinus radiata* and *Pinus pinaster*, and were established by converting native bushland and purchasing farmland. This occurred mainly in the Blackwood Valley, the Donnybrook Sunklands and at Gnangara.

A change of Government in 1983 saw a new policy of prohibiting establishment of plantations on native forest lands. Since then considerable work has been undertaken (initially by CALM, and since 2000 by the Forest Products Commission) to establish plantations on farmland—both as plantations but also as plantings integrated with existing farming activities (Shea and Bartle, 1988; Bartle and Shea, 1989). This involved *P. radiata* and then *Eucalyptus globulus*, with the major aims being to provide fibre resources and environmental co-benefits, such as reducing salinity in water resource catchments.

Table 2 **Areal extent (ha) of plantations in Western Australia (55% of softwood and 2% of hardwood plantations in 2005 are owned by the State Government)**

| Forest type | Year | |
|---|---------------------|---------|
| | 1990 | 2005 |
| Plantations | (ha) | (ha) |
| <i>Pinus radiata</i> and <i>P. pinaster</i> | 94 000 ² | 110 395 |
| <i>Eucalyptus globulus</i> ³ | 7 000 | 259 371 |

Source: Parsons and Gavran, 1995.

Since 1990 several overseas companies have invested in plantations on farmland, which was followed by Australian investment via managed investment scheme companies. This led to rapid expansion in the amount of *E. globulus* planted on farmland, predominantly in the greater than 600 mm rainfall zone. By 2004, 260,000 ha had been established, representing a major change in land-use. The benefits of this widespread reforestation are now apparent in water catchments such as the Denmark River, where considerable reforestation has improved the quality of previously saline water (Bari *et al.* 2004).

With recognition of salinity as a major problem and acknowledgment that trees can assist in restoring landscape hydrology, there were new initiatives by CALM to extend forestry into drier (300-600 mm per year) regions, with both *P. pinaster* (Shea *et al.* 1998) and mallee eucalypts (Bartle, 2001). These initiatives have been continued by the Forest Products Commission.

² Estimate from 1990-1991 Annual Report, CALM.

³ Mainly *Eucalyptus globulus*.

Climate change considerations in forestry planning

SWWA's mediterranean climate has two major features needing consideration to ensure success of plantations. Firstly, there is little reliable rainfall during summer (October to April) and secondly, there are recurrent drought years where winter rainfall is considerably below normal. There have been recurrent episodes of drought-induced tree deaths in a variety of species such as *P. radiata* in the late 1960s, late 1970s and 1987/1988 (McGrath *et al.* 1991), and *E. globulus* in 1994 and 2000 (Harper, McGrath and Carter, 2002; Harper *et al.* 1999; Harper, Smetten and Bartle, cited in Moore, 1998).

Patterns of drought deaths are related to soil and site conditions, and procedures are now in place to avoid sites with inadequate soil water storage capacity (Harper, McGrath and Carter, 2002; Harper, Smetten and Bartle, cited in Moore, 1998; Harper, 1994). Similarly, the amount of water a plantation uses can be manipulated by thinning and fertilisation, with prescriptions developed for major plantation species (McGrath *et al.* 2002). The step-change in rainfall since the 1970s has been taken into account in these prescriptions, as plantations that have been studied have grown during this period of lower rainfall. As a result plantation growth and management techniques are calibrated to this dry period.

Various studies have been undertaken of different regions in advance of plantation development. These studies generally investigate the amount and reliability of rainfall (Butcher, 1986; Harper, McGrath and Maher, 1990), and indeed some studies have taken climate change into account. For example, in 1990 a suitability study of the Esperance area (Harper, McGrath and Maher, 1990) analysed rainfall records from all available stations and redrew rainfall isohyets based on records for the period 1980 to 1989. The rainfall during this period was six per cent lower than in the previous 10-year period. Similar considerations of likely climate changes were made in advance of expanding the maritime pine scheme in 1996.



In addition to the impacts of reduced rainfall, climate change may have other impacts on plantations but the risk of these has not yet been quantified. They include:

- changes in fire hazard because of differences in litter quantity and climatic conditions; and

- changes in the amount of wind-throw (e.g. where trees are blown over) as a result of extreme storms events.

Plantation management and water yield

Catchment water yields can be manipulated by managing forest canopy density, and in the Gnamangara region this technique is being used to improve the groundwater resource, which has been impacted by, among other factors, SWWA's drying climate. There has been a significant decline in groundwater in the Gnamangara region during the past 20 years. This has been attributed to the drier climate, increased interception by vegetation, and groundwater extraction for horticulture and urban use. The reduction in groundwater recharge in this area has occurred under both pine plantations and native woodland systems. Programs to reduce interception and water use in both these systems are being implemented by thinning and clear-felling pine plantations, and through more frequent burning of woodland vegetation to reduce its density. This example illustrates the competition between various land uses for water.

Community consultation sessions during the study also highlighted the competition between forestry operations and water supplies. For example, on the South Coast it is reported that dams near plantations are drying up as a result of decreased rainfall, and water interception and extraction by trees. This is an issue for fire management as the dams would once have provided sufficient water in the event of a fire. However, water tanks are now being built alongside plantations to ensure an adequate water supply in case of wildfire.

Additionally some plantations on the South Coast are planted at the margins in terms of their rainfall requirements for optimum growth. If the rainfall continues to decrease at these locations there will be a major impact on an industry in which people have invested hundreds of millions of dollars.

Carbon sequestration

The promotion of plantations as carbon sinks under Article 3.3 of the Kyoto Protocol is a direct mitigative response to climate change (Schlamadinger and Karalainen cited in Watson *et al.* 2000). It can also act to mobilise capital, as afforestation in higher rainfall areas does, through attracting investment into carbon trading sequestration for the purpose of trading carbon credits. Additional land management benefits will flow from such investment, including improving land and water resources, biodiversity enhancement and protecting rural infrastructure from salinity.

Work to take advantage of this approach commenced with CALM before the Kyoto Protocol was signed in 1997. Two groups of Japanese scientists visited Western Australia in 1994 with a plan for increasing rangeland productivity to sequester carbon and overcome desertification. This interaction led to the concept that profitable plantations could be established in the medium rainfall zone to be used as carbon sinks, which would encourage the widespread reforestation needed to restore landscape hydrology. A scoping document in CALM outlined the benefits of carbon sequestration:

“...a solution would be to encourage the move of the {proponents} afforestation programme to the wheatbelt: here increased carbon fixation would also mean more water use, less salinity and wind erosion... The real bonanza from these proposals will come if we can encourage the Japanese to directly fund large scale afforestation in the wheatbelt as a means of rectifying their environmental concerns (i.e. global carbon imbalance).”⁴

⁴ Memo from R.J. Harper to Executive Director, CALM, 30 November 1995.

A number of discussion documents followed and Australia's first carbon sequestration scheme (involving BP Australia) was established at Katanning in 1998 with afforestation of farmland using *P. pinaster*. This approach has now been adopted elsewhere in Australia and forms part of the basis of the Forest Products Commission's ongoing 'Infinittree' program.

In response to the opportunity this approach provides, considerable investment has been made in determining the amount of carbon sequestered by various tree species. Research on carbon sequestration has been undertaken by CALM and the Forest Products Commission, and through partnership with the now defunct Cooperative Research Centre of Greenhouse Accounting. The research considered forestry aspects of carbon sequestration (Ritson and Sochacki, 2003; Harper, Smetten and Tomlinson, 2006; Harper *et al.* 2003) and impacts on agricultural systems (Webb *et al.* 2000; Harper and Gilkes cited in Lal *et al.* 2001; D'Souza *et al.* 2002; Murphy *et al.* 2002; Harper *et al.* n.d.). Various consultancies have also been completed, including one for Griffin Energy, which extended the carbon sequestration concept and advocated using carbon sinks for restoration and replacement of natural bushland (Harper, 2002) in catchments where biodiversity was at particular risk.

Another response to climate change is to consider alternatives to fossil fuels for energy production. The Forest Products Commission is undertaking considerable work on developing systems of biomass production from farmland (Harper *et al.* 2000; Sochacki, Harper and Smetten, n.d.) and plantation residues (Buckton, 2005) for the production of bioenergy.

The future

It is difficult to determine the impact that climate change has had directly on forestry, both in terms of how it impacts on forestry activities, and how it might drive investment in plantations for carbon sequestration. While climate change and increasing concern about greenhouse emissions seem to have supported forestry to some degree, there have been other major influences such as declining wool prices and consequently availability of pasture land, consolidation of farm holdings, deregulation of national and international capital markets and favourable taxation policies.

It is also difficult for forest managers to plan for future climate change in the absence of clear indications about its direction; that is will it be wetter or drier, hotter or colder? Furthermore, likely climate change interactions, such as the effects of increasing CO₂ concentrations on tree growth rates and susceptibility to frost risk are largely unknown.

In order for forestry to maintain profitability and continue providing a host of environmental benefits, it is essential the likely impacts of climate change on forestry are determined. The forestry sector would benefit from information regarding the effect of changes in rainfall, evaporation and temperature. These are likely to impact growth rates and thus the areal extent of plantations' profitability. Future scenarios also need to consider the impact of fatal events such as drought and how climate changes may increase the risk of disease, fire and wind-throw. With declining rainfall, an additional important issue for forestry with declining rainfall will be competition with other land uses for increasingly scarce water resources in water resource catchments.

FISHERIES

Climate change has not been highlighted as an issue in the Department of Fisheries' Annual Reports or in annual *State of the Fisheries Reports*. Yearly variation in the Leeuwin Current, which is influenced by climate variables, and in turn linked to variation in catch for species such as rock lobster and Shark Bay scallop, has been noted, but a long term-trend has not been identified nor has climate change been a focus of fisheries management in the State. Nonetheless, the Department of Fisheries has been involved in studying the Leeuwin Current and in the national debate on climate change.



Commercial fisheries

The State's commercial fisheries⁵ are comparatively small-scale and take low volume catches of high value product. The catch in 2002/2003 of 34 thousand tonnes constituted less than 14 per cent of the Australian total (ABARE, 2005), which in comparison with the world's fisheries accounts for less than 0.4 per cent (ABARE, 2005). However, Western Australia's fisheries are economically significant. In 2003/2004 wild caught fisheries were the nation's most valuable, contributing 25 per cent of the total value of Australia's fisheries. Significantly, much of the State's fishing fleet is located in regional areas and the fishing industry's contribution to regional economies is important.

The most commercially valuable fisheries in Western Australia are based on:

- capture of western rock lobster from the south and mid west coast;
- prawns of various species principally caught within restricted areas of Shark Bay and Exmouth Gulf;
- scallops, most of which are caught on the mid west coast to Gascoyne area; and
- abalone taken by divers on the reefs of the south and south west coasts.

Recreational fishing

Recreational fishing involves around 34 per cent of the State's population, with an estimated 600,000 Western Australians (up from 284,000 in 1987) and an increasing number of tourists contributing \$500 million per year to the State's economy. Recreational fishing is a significant component of local employment for many regional coastal towns.

Fish stocks supporting recreational fishing are finite, but the number of recreational fishers continues to grow as the State's population and economy expands. There have also been advances in angler efficiency through improved technology and greater fishing pressure has

⁵ Fishery is defined under the *Fish Resource Management Act (FRMA)* as one or more stocks or parts of stocks of fish that can be treated as a unit for the purposes of conservation or management; and a class of fishing activities in respect of those stocks or parts of stocks of fish.

been placed on limited fish resources. Fishing effort is highest in the more heavily populated south of the State. The west coast bioregion (roughly Port Gregory to Augusta) continues to be the most significant recreational fishing area, where 68 per cent of the recorded effort (an estimated 5.6 million fishing days) took place during 2003/2004 (Penn, Fletcher and Head, 2005).

Determining the impact of climate change

Marine fisheries

Western Australia's fisheries and the ecosystems that support them are strongly influenced by the presence of the Leeuwin Current, which is the dominant oceanographic feature on the west coast. The current influences overall oceanic productivity and has a range of impacts on individual species, particularly in terms of distribution and success of breeding seasons.

Variation of the Leeuwin Current causes variability to fisheries, and understanding this is important for better managing commercial and recreational fishing. Since the 1980s a number of research projects have identified links between variation in the current and recruitment success and distribution. Western Australia has some historical records of catch and effort but the most available and complete data is limited to the period from 1975. As a result we do not have, at this time, direct local evidence as to what pattern of variability has applied to the marine waters of Western Australia over the past several hundred years. Consequently it is difficult to make determinations about the direct impacts of climate change on fisheries.

Only for a few fisheries is there sufficient understanding of recruitment variability to provide indications of impacts and adaptation with regard to climate change. However, to date an investigation of these links has not been undertaken.

Western rock lobster

The Department of Fisheries attended a CSIRO-hosted workshop on the impact of climate change on the fisheries sector in 1991. The western rock lobster fishery was discussed in detail, including consideration of management responses to climate change. It was noted that because it is an economically valuable fishery, resources have been available over a number of decades to fund an extensive research program directed at the western rock lobster fishery. Catch and effort records for the western rock lobster fishery go back to 1945 and there has been extensive research undertaken. The records show that recruitment and growth of rock lobsters is variable and strongly influenced each year by the strength of the Leeuwin Current. Fisheries managers take this into account and a method has been developed to predict, up to four years in advance, the number of lobsters that will meet the legal catch size requirement each year.

Research and management are integrated so that monitored changes in recruitment of juvenile rock lobsters (due to environmental conditions or to fishing pressure) trigger a management response designed to adjust fishing effort to maintain the breeding stock at target levels. The fishery is able to cope with moderate environmental variability and the management arrangements are capable of adjusting to negative or positive impacts of climate variability (and climate change) on stock recruitment.

Participants at the workshop were informed that climate change presented two challenges to the ongoing management of the fishery. Firstly, management is based on mathematical modelling of the rock lobster stock, which in turn is based on analysis of historical data, and

consequently, there is a need to update and refine the model in response to climate change as it impacts on the marine environment.

Secondly, long term changes that result in changes to inshore habitat, such as seagrass beds and reefs, will have impacts on the fishery. To understand these impacts it is necessary to conduct baseline surveys and follow up with monitoring to detect changes. Associated with this is the need to monitor physical and chemical parameters of the marine environment (e.g. acidity, current velocity) at the regional scale as well as the local coastal scale.

During the 15 years since the CSIRO workshop, the rock lobster fishery model has been continually updated. However, baseline surveys of inshore habitat have only been progressed recently (in particular through Australian Government-funded initiatives such as the Ocean Futures project, which is funded through the Natural Heritage Trust), and with only limited local exceptions, researchers still do not have an understanding of what habitat changes have occurred in recent years along the South West coast. Similarly detailed monitoring of oceanic conditions has only recently begun as part of the State and Australian Government collaboration on the Strategic Research for the Marine Environment (SRFME) project.

Other species affected by the Leeuwin Current

There is also reasonable evidence that the Leeuwin Current affects the pilchard and scaly mackerel fishery. As scaly mackerel are a tropical species, their distribution further south is governed by the presence of warmer water. In years of a strong Leeuwin Current the number of scaly mackerel caught within west and south coast fisheries is considerably increased. During weak current periods the mackerel appear to be dispersed further from the coast.

The full impacts of the current on egg dispersal, juvenile development, and distribution of pilchards and scaly mackerel have not been fully investigated. There is insufficient information to determine management procedures to offset the effects of the Leeuwin Current on either of the above two issues and the effects are negated once the current has returned to a 'normal' pattern. Therefore it is considered to only have a negligible impact on the fishery at present levels of climate variability. Ongoing monitoring will be necessary in the face of climate change.

The lower west coast of Western Australia is unique in terms of the spatial overlap of pilchards and scaly mackerel, two similar sized species of sardines. Pilchards are a warm-temperate species with their distribution in Western Australia extending only as far north as Geraldton, whereas scaly mackerel are a tropical sardine, distributed only as far south as the Perth metropolitan region. Both are typical of many small pelagic fish of the herring and sardine family in that they can respond rapidly to changes in conditions in their environment, such as changes in temperatures and food availability.

Other examples of fish strongly influenced by the Leeuwin Current include white bait and Australian salmon. In the case of whitebait a strong relationship exists between the annual catch variations and the strength of the Leeuwin Current during the previous year when spawning occurred. Thus, the stronger the Leeuwin Current, the greater the relative catch of whitebait in the following year.

The abundance of juvenile Australian salmon in South Australia is also linked to the Leeuwin Current. Fluctuations in recruitment and catches of the west coast salmon fishery may also be associated with variations in the strengths of the Capes Current and the Leeuwin Current—when the Leeuwin Current is flowing strongly and warmer waters penetrate onto the continental shelf, it is thought that the fish may simply migrate offshore into deeper cooler waters rather than continue to migrate around the coast.

Inland and estuarine fisheries

There are no commercial fisheries in inland rivers and lakes of SWWA. However there is strong community interest in recreational fishing, particularly for marron in rivers and creeks, and to a lesser degree for trout in artificially stocked rivers and dams.



Estuarine fisheries, which are inherently productive environments with relatively high nutrient water compared to marine waters, have historically been important for providing fresh seafood to population centres in SWWA. However, with increased residential and tourism developments along the south west coast, commercial estuarine fisheries are declining and recreational fisheries and associated tourism is gaining in importance.

SWWA's declining rainfall during the last 35 years is of significance to freshwater fisheries, particularly the marron fishery (which has declined from a peak of around 120 tonnes a year in 1960 to 5.8 tonnes in 2003). Declining rainfall also affects estuarine fisheries as it reduces estuarine inflows, which leads to decreased scouring and flushing, and a build-up of nutrients. Under certain conditions this can cause stagnation and stratification of estuarine waters, algal blooms and hypoxia, which in turn causes fish kills and loss of productive habitat. There is mounting evidence that vulnerable species of fish are becoming less numerous or are in danger of being lost from some of SWWA's estuaries.

The future of some of the South West's endemic fish species is also of concern in light of the declining rainfall.

Potential industry impacts

While Western Australia has not experienced severe impacts on fisheries as a result of climate change, it has experienced the sudden collapse of a fishery and understands the resultant impacts on the industry. The south coast pilchard fishery based at Albany collapsed as result of a fish disease and the industry witnessed the economic and social hardship of the people dependent upon that particular fishery. The disease caused a sudden and dramatic reduction in catch quotas, which unexpectedly struck the thriving fishery. The State Government implemented a range of management and adjustment strategies including a Fisheries Adjustment Scheme and financial assistance package.

This example highlights the potential impact on the fisheries industry and the State as a result of crossing a particular threshold. It also suggests that work may need to be done in refining management and adjustment schemes as adaptation responses to the increased risk of climate change.

The future

Climate change can be expected to bring about change to sea surface temperature and the presently prevailing pattern of oceanic currents. This may in turn have an impact on the distribution, breeding success and growth of a large number of species. It would also impact on critical marine ecosystems, such as seagrass beds. For SWWA impacts on the Leeuwin Current could have adverse impacts for one of the country's most valuable fisheries—the western rock lobster.

An understanding of how climate change may change the relative frequency and intensity of El Nino and La Nina expressions of the Southern Oscillation, which in turn affect the Leeuwin Current, is therefore important for determining changes that may be expected for Western Australia's marine fisheries so that adaptive measures can be developed and implemented.

PUBLIC HEALTH

The Department of Health is responsible for providing a wide range of health services for Western Australia as well as promotion and protection of peoples' health. This is achieved through a range of services including:

- public health and preventative measures to protect the community and promote health;
- the provision of acute and chronic health care services; and
- rehabilitation and domiciliary care services.

Assessing public health from 1960 to now

Consideration of SWWA's population and health characteristics before the 1970s and in recent times may provide some indication of the impacts of climate change. The following section compares characteristics of each sector during 1960 with that of 2004 to provide a broad overview of the health sector for each of these years. However, a detailed assessment of climate impacts on health is very difficult at this point given the nature of health data (which is collected for health specific issues), and the diverse range of variables impacting on human health and wellbeing, of which climate is only one.

1960

Western Australia's population has grown rapidly since 1960 as has health care knowledge and application, with many new technologies and systems now available to the public that were unheard of in the 1960s. In 1960:

- Western Australia's population grew from 718 830 in 1959 to 731 403, an increase of 1.75 per cent of which 374 654 were males and 356 749 females;
- the birth rate was 23.14 per 1000 and the death rate was 7.79 per 1000, with a natural increase in births over deaths of 1.52 per cent;
- maternal mortality was 0.47 per 1000 live births and the infant mortality rate was 21.62 per 1000 live births; and
- the three main causes of death from notifiable infectious disease were tuberculosis, infantile diarrhoea and rheumatic fever (Department of Public Health, 1960).

2004

By the end of 2004, Western Australia's population (ABS, 2005) stood at 1 994 000 (with almost equal numbers of males and females), and during the following quarter to the end of March 2005 it exceeded two million persons. This milestone was reached with a growth rate of 0.5 per cent (9800 persons) from the December quarter 2004. Net overseas migration was the largest contributor to Western Australia's population during this quarter (57.9 per cent), followed by natural increase and net interstate migration. There were around 11 000 deaths, including 99 infants.

The sectors involved in providing health care services have also evolved. Protection of public health is given high priority and many groups within government and the private sector have been established to address health care needs of specific sectors of the community or specific health outcomes. Similarly, clinical components of health care have become more comprehensive in response to growth in knowledge and technology.

Public health and climate change

Much consideration has occurred worldwide on the potential health impacts that could arise from global climate change. These are well documented and indicate that changes in climatic conditions can have three kinds of health impacts (World Health Organisation, 2003). These are those that are:

1. relatively direct, usually caused by weather extremes;
2. consequences of environmental change and ecological disruption in response to climatic changes; and
3. consequences that occur when populations are demoralised and displaced as a result of climate change induced economic dislocation, environmental decline and conflict situations. It can include traumatic, infectious, nutritional, psychological and other health consequences.

Potential environmental outcomes as a result of climate change and the means through which impacts on human health can occur are shown in **Figure 13** below.

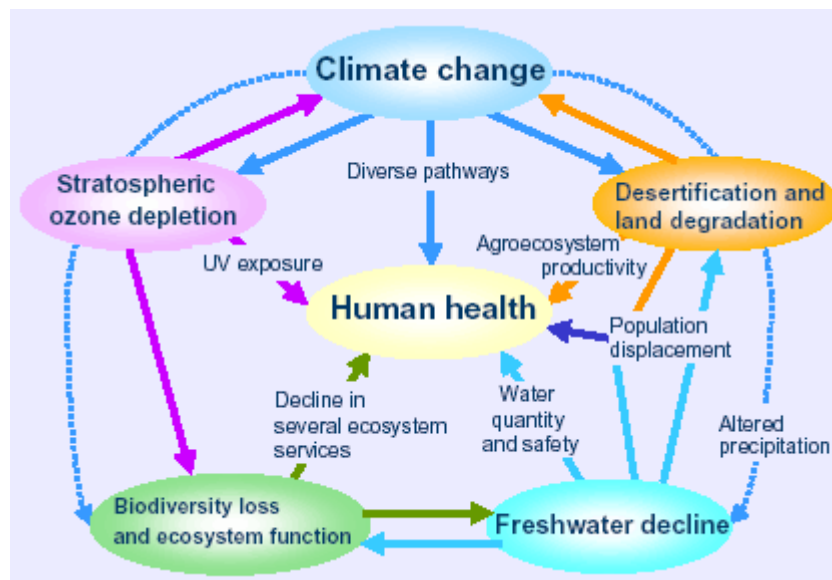


Figure 13 Links between climate change, environmental outcomes and human health.

Source: World Health Organisation.

Additionally, there are several pathways by which climate change can impact on human health as shown below in **Figure 14**.

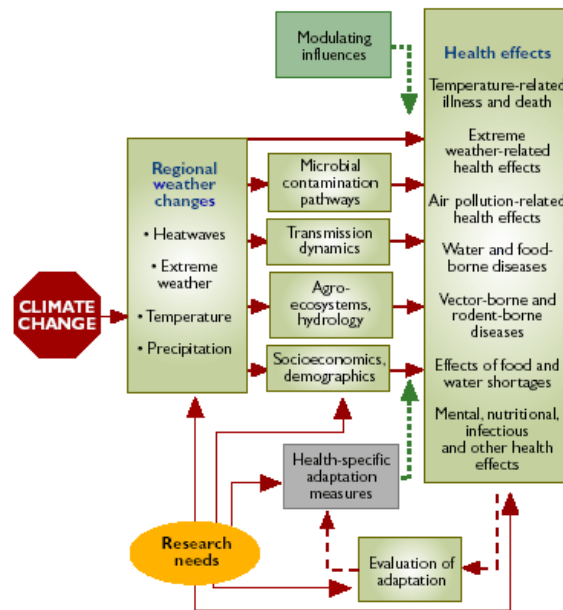


Figure 14 Pathways by which climate change affects human health.

Source: World Health Organisation, 2005.

The Department of Health and climate change

Most of the Department of Health's activities occur in response to particular events such as an infectious disease outbreak, or in recognition of particular circumstances such as road accidents or cigarette smoking.

In relation to recognised links between climate change and health, these are largely incidental. Links between a climatic event and a health outcome such as being hit by falling debris in a storm may be recorded in patient records but these records are incidental to the primary purpose of the medical response; that is treating the injured or ill person.

The Department of Health has recognised that potential health impacts may arise from climate change in Western Australia (including SWWA) and that it needs to be prepared for possible changes required to the health care system. It is currently embarking on a program that will consider short and long term implications for the health and wellbeing of the Western Australian community, as well as requirements for possible adaptations within its activities. However, no specific focus has been applied to date on previous links between climate change that has occurred in SWWA and health outcomes.

Analysing impacts of climate change on health

An analysis of health impacts arising from climatic changes may lend itself towards better understanding future health impacts. The World Health Organisation (WHO) has reviewed the potential requirements for monitoring of health impacts associated with climate change and indicated the data required for monitoring climate effects on health, which include:

- climatic variables;
- population health markers; and
- other factors that may also influence the outcomes.

A modified version of these requirements is shown in **Table 3**.

Table 3 **Data required to monitor climate change impacts on human health**

| | Thermal extremes | Extreme weather events (floods, high winds, droughts) | Food and waterborne disease | Vector-borne disease |
|--|---|---|--|---|
| Principal health outcomes | Daily mortality; hospital admissions; clinic/emergency room attendance. | Attributed deaths; hospital admissions; infectious disease surveillance data; mental health; nutritional status. | Relevant infectious disease deaths and morbidity. | Vector populations; disease notifications; temporal and geographical distributions. |
| Which populations/ locations to monitor | Urban and rural populations. | Urban and rural populations. | Urban and rural populations. | Margins of geographical distribution and temporality in endemic areas. |
| Sources/methods for acquiring health data | State death registries (including city and regional specific data). | Use of State death registries; local public health records. | Death registries; State surveillance notifications. | Local field surveys; routine surveillance data (variable availability). |
| Meteorological data | Daily temperatures (min/max or mean) and humidity. | Meteorological event data: extent, timing and severity. | Weekly/daily temperature; rainfall for water-borne. | Weekly/daily temperature, humidity and rainfall. |
| Other variables | Confounders: influenza/ respiratory infections/air pollution. Modifiers: air conditioning (work and home and availability of water supplies. | Disruption/contamination of food and water supplies; disruption of transportation. Population displacement. The above parameters will have an indirect impact on health. | Long term trends dominated by host- agent interactions whose effects are difficult to quantify. Indicators may be based on examination of seasonal patterns. | Land use; surface configurations of freshwater. |

Source: Modified from the World Health Organisation.

The WHO (2003) recognises the complexities associated with monitoring impacts of climate change on health and indicated that programs must consider the following issues:

(i) Distinguishing apparent from real ‘climate change’

Climate is naturally variable and many health indices demonstrate seasonal and inter-annual fluctuation. The demonstration of such a relationship provides no direct evidence that climate change has occurred or not occurred—rather, it may merely confirm that these diseases have a seasonal or climatic dependence.

An excess of heat-related deaths in a particularly hot summer, or even a succession of hot summers, indicates the potential for climate change to increase mortality, but it does not prove that mortality has increased as a result of climate change. This would require evidence of a change in the 'baseline' climate conditions, i.e. that the sequence of hot summers was exceptional, and due to climate change rather than random variation.

(ii) Attribution

Since climate is one of many influences on health, the attribution of an observed change in population health to an associated change in climate is not straightforward. The influence of concurrent changes in other environmental, social or behavioural factors must first be taken into account.

(iii) Effect modification

Over time, as the climate changes, other changes may also occur that alter the population's vulnerability to meteorological influences. For example, vulnerability to extreme weather events, including floods and storms, will depend on where and how residential housing is built, what flood protection measures are introduced, and how land use changes. Effective monitoring must include parallel measurements of population and environmental data, to allow study of potential modifying influences.

Table 4 below provides an overview of each of the health areas potentially affected by climate change in SWWA and potential or actual impacts to the community and the Government.

Table 4 **Health areas potentially impacted by climate change**

| |
|--|
| <p>General principles</p> <p>The principal criteria for selecting diseases and settings for monitoring should include the following:</p> <ul style="list-style-type: none"> • Evidence of climate sensitivity—to be demonstrated through either observed health effects of temporal or geographical climate variation, or evidence of climate effects on components of the disease transmission process in the field or laboratory. • Significant public health burden—monitoring should be preferentially targeted towards significant threats to public health. These may be diseases with a high current prevalence and/or severity, or considered likely to become prevalent under conditions of climate change. • Practicality—logistical considerations are important given that monitoring requires dependable and consistent long-term recording of health-related indices and other environmental parameters. Monitoring sites should be chosen where change is most likely to occur, but where appropriate capacity for reliable measurement exists. The choice of non-climatic variables will depend on the specific disease, but the principal categories of confounding or modifying factors include: <ul style="list-style-type: none"> ➤ age structure of population; ➤ underlying rates of disease, especially cardiovascular and respiratory disease and diarrhoeal illness; ➤ level of socio-economic development; ➤ environmental conditions, e.g. land-use, air quality, housing conditions; ➤ quality of health care; and ➤ specific control measures, e.g. vector control programs. |
|--|

Source: World Health Organisation.

Temperature health impacts

Global studies show an association of increased mortality with exposure to prolonged and extreme heat among populations where environmental temperature is above levels to which they are accustomed. Urban populations are the most vulnerable to adverse heat-related health outcomes as are the elderly, young children, socio-economically disadvantaged, and people who are bedridden or are on medication.

In Western Australia, hospitalisation and death records indicate relatively few cases directly involving exposure to excessive heat as a cause in recent years. Death records (available

back to 1980) could be used to identify excess mortality during heatwaves by comparing data at the time of the heatwave with data from previous years. Hospitalisation and Emergency Department data would not be as useful because the numbers of hospital admissions over time are influenced by factors in addition to environmental conditions, including referral patterns and hospital admission practices.

Table 5 **Temperature related health impacts**

| |
|--|
| <i>Impacts for DOH</i> <ul style="list-style-type: none">• Increased hospitalisation.• Increased Emergency Department attendances.• Heatwave emergency plan.• Heat illness management plans. <i>Impacts for the community</i> <ul style="list-style-type: none">• Increased mortality or morbidity of vulnerable populations.• Design of buildings to reduce heat retention.• Behavioural adaptations, including increased air conditioning and fluid intake.• Education of populations at risk. |
|--|

Extreme weather-related health effects

Associations can be demonstrated between extreme weather events and levels of morbidity and mortality within given populations. Vulnerability is related to proximity to extreme weather occurrences and levels and types of protective measures in place. The types of extreme events such as storms, both on land and along the coast, high winds and wave surges or droughts can influence the type of health outcome.

In Western Australia, hospitalisation and death records indicate relatively few cases directly related to extreme weather events as a cause in recent years. Death records (available back to 1980) could be used to identify excess mortality during extreme weather events by comparing data at the time of the event with data from previous years.

Table 6 **Extreme weather related health impacts**

| |
|---|
| <i>Impacts for DOH</i> <ul style="list-style-type: none">• Increased hospitalisation.• Increased Emergency Department attendances.• Extreme weather emergency management plans. <i>Impacts for the community</i> <ul style="list-style-type: none">• Increased mortality and morbidity of vulnerable people.• Possible social disruption and dislocation.• Behavioural adaptations.• Education of populations at risk. |
|---|

Air pollution-related health effects

Associations between air pollution and health effects require studies to correlate air pollution measurements with health outcomes such as mortality and hospitalisation for specific diseases, including cardiovascular and respiratory disease. Vulnerable groups include the elderly, children and people with chronic lung or heart disease.

Table 7 Air pollution related health impacts

| |
|---|
| <p>Impacts for DOH</p> <ul style="list-style-type: none"> • Increased hospitalisation. • Increased Emergency Department attendances. <p>Impacts for the community</p> <ul style="list-style-type: none"> • Increased mortality and morbidity of vulnerable populations. • Behavioural adaptations. • Education of populations at risk. |
|---|

Water and food-borne disease health impacts

Adverse impacts on water and food supplies arising from climate change during the past 40 years and subsequent health outcomes may be difficult to determine. Changes in the incidence of hospitalisations and/or deaths from food or water borne disease have been influenced by many factors including behavioural changes with respect to food preparation and consumption, improved laboratory techniques and better reporting to surveillance systems that have occurred during the past half century. Vulnerable groups include urban populations.

The rates of infections of specific gastrointestinal infections of species such as *Salmonella* or *Campylobacter* linked to seasonal circumstances may provide useful data but confounding factors need to be identified and included in analyses.

Table 8 Water and food-borne health impacts

| |
|---|
| <p>Impacts for DoH</p> <ul style="list-style-type: none"> • Increased hospitalisation. • Increased Emergency Department attendances. <p>Impacts for the community</p> <ul style="list-style-type: none"> • Increased mortality and morbidity of vulnerable populations. • Behavioural adaptations. • Education of populations at risk. |
|---|

Vector-borne disease health impacts

Ross River Virus (RRV) disease and Barmah Forest Virus (BFV) disease are the major mosquito-borne diseases occurring in SWWA, occurring in environmentally-driven cycles with major outbreaks every three or four years. RRV disease became notifiable in 1985 and BFV disease in 1994, although prior to the diseases being declared notifiable there were occasional outbreaks.

Some recent outbreaks of RRV disease in SWWA have been linked to above average spring rainfall, above average daily temperatures or short-term rises in sea-level associated with La Niña events. However, several factors may confuse the interpretation of the human case statistics, including:

- the proportion of cases of disease being notified may have changed over time;
- patient and doctor awareness;
- availability of specific serological testing; and
- urban development and recreation near to wetland breeding sites may have increased human exposure to vector mosquitoes.

Therefore it is not possible to directly link past trends in mosquito-borne disease incidence with climate change in SWWA. For example, a record number of cases of Ross River Virus have been notified for the Peel Region during 2005/2006 but there is no evidence that this is related to climate trends. Since the opening of the Dawesville Channel in 1994 and the resulting higher tidal amplitude inundating salt-marsh mosquito breeding areas there has been an increase in the number of mosquitoes in spring and summer and in the regular occurrence of RRV cases. In 10 to 15 years, with the benefit of 30 years of human case data for RRV, any trends attributable to climate change may become apparent.

Since the early 1990s there has been a considerable increase in resources contributed by State and local government for mosquito management in the worst-affected areas. This has been principally due to a greater awareness of RRV and BFV diseases, identification of the major vector mosquito species and their breeding sites and expansion of residential development in regions affected by nuisance and disease vector mosquitoes.

The exotic dengue mosquito, *Aedes aegypti*, occurred in the South West until the late 1960s, and cases of dengue fever occurred during this time. A concerted effort was made with the Mosquito Eradication Campaign during the mid 1980s to remove man-made mosquito breeding sites from towns and communities to limit the reintroduction of the vector and to prevent dengue fever outbreaks. Future climate change, along with increasing opportunities for the reintroduction of the dengue mosquito and the availability of an increasing number of suitable breeding sites such as rainwater tanks (as an indirect consequence of adaptation to changing water regimes), may lead to dengue fever resurgence.

Table 9 **Vector-borne disease health impacts**

| |
|---|
| <p>Impacts for DoH</p> <ul style="list-style-type: none"> • Hospitalisation of serious cases. • Funding of mosquito and virus surveillance. • Funding for local government mosquito management programs. • Provision of training and advice on mosquito management. <p>Impacts for the community</p> <ul style="list-style-type: none"> • Debilitating illness. • Negative impacts on tourism. • Negative impacts on real estate values. |
|---|

Indirect health effects

Anecdotal evidence suggests that indirect health outcomes may have arisen. These are linked to changed climatic conditions. Many may have occurred after enhanced environmental conditions for pathogen proliferation. Indirect social effects can have significant adverse health outcomes but the full effects of these may not be realised for many years. Indirect adverse health impacts could arise from:

- increased use of air conditioners/humidifiers;
- increased use of mulches in gardens for water conservation;
- increased recreational inland water body use;
- increased UV radiation (outdoor exposure);
- increased UV radiation (cosmetic/skin tanning);
- changes to land use and population displacement;
- changed food/nutritional quality; and
- disrupted food and water supplies.

The future

Impacts to health can occur as a result of climatic conditions. However it is very difficult to demonstrate that actual disease outcomes in the previous 45 years are linked to specific trends in climate change. There are many factors that influence disease outcomes and the causal links between disease outcomes and external effects are often difficult to verify.

Often complex epidemiological studies are required in order to find the potential causes of specific disease outcomes. Although exposure to a specific environmental factor may be suspected as a causal factor, sound science would not use presupposition of specific factors as its basis. Notwithstanding this, links between past climatic events and health outcomes could be examined. However, assumptions that the outcomes are based solely on climatic conditions should be treated with caution.

Climate change will become more of a challenge to human health in the future. This study is a first step in addressing the vulnerability of the health sector to climate change. Further work needs to be undertaken to address the statistical correlation between climate change and health impacts.

TOURISM

SWWA contains some of the State's most notable tourism destinations. For example:

- Margaret River has developed a sophisticated image based on the region's wineries and beauty of its forests and coastline;
- coastline stretching from Dunsborough to Bunbury has an image as a family-focused coastal destination;
- the wheatbelt region is largely a drive destination focused on the area's cultural and agricultural heritage and seasonal wildflowers;
- the southern forests region, including the towns of Pemberton, Manjimup and Denmark, has built a thriving tourism industry around the region's national parks; and
- the coastline north of Perth to Geraldton has traditionally been a low key, coastal holiday destination for intrastate tourists from Perth and the wheatbelt.

These destinations and their natural attributes are key drivers for tourism visitation and, therefore, the future impact of climate change on them may pose significant risks for the region's tourism potential.

1960s to 2005—from infancy to major industry

The meteoric growth of tourism in Western Australia during the past 40 years has masked any observable impacts which climate change may have caused for the industry.

Mass tourism is largely a modern phenomenon. Tourism in Western Australia was in its infancy back in the 1960s, with the Western Australian Tourist Development Authority (now Tourism Western Australia) only established in 1959. Accurate visitor statistics for Western Australia were unavailable until the early 1970s, and the methodology of collection has changed significantly, making statistical comparison difficult.

In the past 40 years tourism as an industry sector has grown from almost nothing to being a crucial economic contributor to Western Australia and the South West. Based on available statistics interstate visitation to Western Australia has increased by as much as three times since the early 1970s. International visitation to Western Australia has increased by as much as 11 times during the same period.

Importance to the local economy

An Access Economics analysis in 2001/02 estimated that tourism generated approximately \$3.6 billion from visitor expenditure, contributing 5.5 per cent of Western Australia's Gross State Product. The industry employs approximately 72,000 people, or eight per cent of the State's workforce.

Approximately 78 per cent of the State's total tourism expenditure and employment is generated in the South West (Access Economics, 2003). This equated to around \$2.7 billion in visitor expenditure or more than 55,000 jobs. In shires with a high tourism focus, between eight and 10 per cent of total regional employment is generated by tourism. In shires with few tourism assets or established infrastructure the percentage is below five per cent. Most industry activity is based on small regionally-based businesses. The Tourism Council of Western Australia estimates there are approximately 4000 tourism businesses in the State.

Links with other sectors

The linking of tourism with other regional industries has grown more complex during the past 40 years. Access Economics analysed the individual industry sectors that benefit from tourism expenditure within the South West, and the important regional economic linkages and multipliers generated by tourism.

Table 10 below indicates the contribution tourism makes to other industries, which could be affected if the industry experiences a downturn.

Table 10 **Tourism expenditure by industry category**

| Supply side industry | Orange Zone value added (\$m) | Green Zone value added (\$m) | Blue Zone value added (\$m) |
|---------------------------------------|-------------------------------------|------------------------------------|-----------------------------------|
| Agriculture, forestry, fishing | 37 | 9 | 5 |
| Mining | 2 | 0 | 0 |
| Food products | 43 | 18 | 9 |
| Beverages and tobacco products | 28 | 11 | 5 |
| Textiles, clothing and footwear | 13 | 3 | 2 |
| Wood products | 0 | 0 | 0 |
| Paper products, printing, publishing | 15 | 3 | 2 |
| Petroleum products | 4 | 2 | 1 |
| Chemicals and plastics | 9 | 2 | 1 |
| Non-metallic products | 0 | 0 | 0 |
| Metal products | 1 | 0 | 0 |
| Transport equipment | 8 | 2 | 1 |
| Other machinery and equipment | 7 | 2 | 1 |
| Over manufacturing | 5 | 1 | 1 |
| Electricity, gas, water | 1 | 0 | 0 |
| Residential building | 0 | 0 | 0 |
| Other construction | 0 | 0 | 0 |
| Wholesale trade | 62 | 14 | 8 |
| Retail trade and takeaway food | 177 | 67 | 27 |
| Repairs | 9 | 4 | 2 |
| Accommodation, cafes, restaurants | 224 | 94 | 42 |
| Land transport | 72 | 8 | 5 |
| Air and water transport | 264 | 21 | 13 |
| Services to transport | 48 | 16 | 23 |
| Communication services | 38 | 9 | 5 |
| Banking | 0 | 0 | 0 |
| Other financial services | 1 | 0 | 0 |
| Ownership of dwellings | 97 | 22 | 12 |
| Business and property services | 28 | 3 | 3 |
| Government administration and defence | 8 | 2 | 1 |
| Education | 82 | 12 | 4 |
| Health and community services | 49 | 11 | 6 |
| Cultural and recreational services | 53 | 12 | 8 |
| Personal and other services | 7 | 2 | 1 |
| Total | 1392 | 351 | 187 |

Orange Zone—Perth and surrounds including Mandurah and Northam.

Green Zone—south west including Bunbury, Albany and Margaret River.

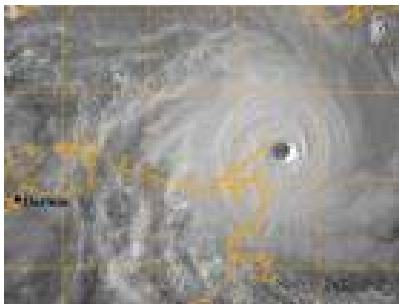
Blue Zone—west coast strip about 150 km wide from north of Perth to Exmouth, including Geraldton and Carnarvon.

Infrastructure development

During the past 40 years, tourist infrastructure such as accommodation, transport infrastructure and tourist attractions have been developed in SWWA. Initially this focussed on establishing infrastructure such as caravan parks, sealed roads and basic visitor facilities. In recent years, infrastructure development has focussed more on upmarket accommodation, visitor attractions and accompanying services such as restaurants, wineries and retail precincts.

Impact of natural events on tourism

Storms and cyclones



Significant tourism development has occurred in coastal areas stretching from Margaret River to Geraldton. Much of this may be at risk due to rising sea levels and storm events. Recent cyclonic events in the State's north indicate the potential impacts of such events.

In March 1999 Cyclone Vance caused major structural damage to 10 per cent of buildings in the tourist town of Exmouth. The combination of very high seas and high tides caused severe erosion of the beachfront and marina. Water and power supplies were cut in some areas for more than a month (Department of Industry and Resources, 2003). Tourism businesses were forced to close and rebuild at the height of the annual peak whale shark tourist season. The total reconstruction cost for the region was estimated at approximately \$35 million (Insurance Disaster Response Organisation, 2004). Economic losses from the closure of the tourist industry during the peak tourism season added to the damages bill.

In April 2000 Cyclone Rosita destroyed the Ecobeach Tourist Resort south of Broome, which had been built to withstand Category Three winds (Bureau of Meteorology, 2005). It is yet to be rebuilt. In March 2005 Cyclone Ingrid caused major damage to Faraway Bay Wilderness Camp and Emma Gorge, part of the El Questro Tourist Wilderness Park in the Kimberley. Faraway Bay was able to reopen in time for the tourist season. Emma Gorge remained closed throughout the 2005 tourist season, causing great disruption to the tour companies. These examples highlight the residual impacts of extreme weather events on tourism. Not only is damage caused by the event itself, but the industry continues to suffer while infrastructure is re-established.

Storm activity has also damaged tourist infrastructure in SWWA. The Busselton Jetty has been severely damaged by remnants of tropical cyclones in 1937 and 1978 (Bureau of Meteorology, 2005). An \$18 million rescue package is currently underway to restore this local attraction.

Rottnest Island has been severely impacted by winter storm activity, most recently in May 2003 when gale force winds, large swells and heavy rainfall caused erosion and damage to roads, shelters and jetties requiring major reconstruction works (Rottnest Island Authority, 2003).



Figure 15 Exmouth after Tropical Cyclone Vance, 1999.

Source: Bureau of Meteorology.

In the future, climate change may impact on the operational costs of tourism enterprises in areas such as insurance, the cost of which may rise with increasing incidence of extreme weather events. Research is required to analyse the likely impacts on the operation of tourism businesses and the willingness of investors to invest in tourism infrastructure in the face of these likely impacts. Governments may need to consider if assistance is required to support tourism in areas where rising costs resulting from climate change will limit industry development.

Bushfires

Bushfires can have a major impact on the tourism industry. Fires in the Perth Hills in the past five years have caused significant damage to the overnight shelters on the state's premier walking trail, the Bibbulmun Track. Lake Jasper, a popular location in the D'Entrecasteaux National Park has only recently re-opened to tourists following fires in November 2004.

Fire can also impact on the environmental and aesthetic values of a tourist region, and discourage people from travelling to the destination. The Blue Mountains in New South Wales experienced major bushfire events in 2001 and 2002, after which tourist visitation fell markedly both during and after the events, with images of the destruction discouraging people from travelling to the area, despite major parts of the region being unaffected.

High value tourist areas such as the karri and tingle forests are particularly sensitive to fire damage. Drying and warming of SWWA's climate is likely to increase the incidence of bushfires and threaten the forest environments on which the region's tourism is based (Carlson and Wood, 2004).

Drought

Drought is a double-edged sword when it comes to tourism. Agriculturally-based regional economies often rely on alternative forms of income such as tourism in times of drought. Tourism however can place significant additional pressure on local water supplies during times of drought, and may impact on the carrying capacity of certain natural areas.



Drought also impacts on visitor perceptions of a destination.

The recent prolonged drought in eastern Australia has had significant effects on tourism, and local community attitudes to tourism. Tourism Alliance Victoria developed an issues paper in 2004 on the impacts of the drought on tourism in regional Victoria. The report found visitation declined between 10 and 50 per cent in a number of drought affected shires. Reasons for decline included adverse media reports, closure of water recreational areas and fishing spots, decline in seasonal gardens and threat of blue green algal blooms. The ability to service tourists in times of drought was also raised, with concerns about supply of potable water, ability to treat sewerage and tourist demand for water intensive facilities such as spa baths (Tourism Alliance Victoria, 2004). No formal studies have been done on the impact of drought on tourism in regional Western Australia.

Continued rainfall decline may impact on the environmental values of some key natural tourism assets of SWWA. Where changing climatic conditions impact on biodiversity, there may also be impacts on the appeal of the destinations containing these assets, particularly the region's tall forests and fauna. Rainfall decline may also impact on rural industries which have a mutually beneficial relationship with tourism. For example, the continued success of wine growing regions such as the Swan Valley, Margaret River and Mt Barker are strongly linked to ongoing tourism growth.

On the positive side, warming and drying trends may extend the tourism season, and attract more visitors to coastal regions which offer 'sun and sand' experiences. Climate change may also enhance conditions for wildflowers, which currently attract significant numbers of visitors to drier areas north and east of Perth. A drying climate may also reduce the spread of dieback which is impacting on the environmental and aesthetic values of large areas of SWWA's forests.

Many Western Australian tourist regions rely on intrastate travel of regional residents. In times of economic hardship, the disposable income within rural and regional communities reduces, impacting on the number of Western Australians holidaying in their own State.

While it is difficult to isolate the reasons for fluctuations in intrastate travel, Table 11(a) and (b) indicates that travel out of the Golden Outback region, which includes large areas of the wheatbelt, was at its lowest levels in the past seven years in 2000 and 2002, coinciding with the major periods of drought. Anecdotal evidence also indicates that coastal destinations such as Busselton have experienced a downturn this year, as the current drought impacts on the travel intentions of wheatbelt farmers.

Table 11(a)&(b) **Intrastate visitors and visitor nights by origin**

| Home/origin of visitor | Year | | | | | | |
|----------------------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
| | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 |
| Australia's Coral Coast | 299 | 289 | 244 | 268 | 309 | 346 | 277 |
| Australia's North Coast | 199 | 269 | 179 | 282 | 233 | 228 | 236 |
| Australia's South West | 929 | 948 | 954 | 934 | 1005 | 967 | 958 |
| Experience Perth | 3 302 | 3 496 | 3 472 | 3 783 | 3 883 | 3 354 | 3 445 |
| Australia's Golden Outback | 576 | 516 | 502 | 594 | 498 | 535 | 584 |
| Other WA | 172 | 19 | 7 | 6 | 9 | 11- | |
| Total | 5 477 | 5 538 | 5 358 | 5 867 | 5 937 | 5 440 | 5 501 |

| Visitor nights generated | Year | | | | | | |
|----------------------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 |
| Australia's Coral Coast | 1 129 | 1 467 | 964 | 1 045 | 1 477 | 1 357 | 1 082 |
| Australia's North Coast | 807 | 1 374 | 1 045 | 1 060 | 1 276 | 1 133 | 1 301 |
| Australia's South West | 2 973 | 3 009 | 3 122 | 2 889 | 3 350 | 2 927 | 3 423 |
| Experience Perth | 12 161 | 12 438 | 13 159 | 12 537 | 13 048 | 12 672 | 12 905 |
| Australia's Golden Outback | 2 148 | 1 924 | 1 755 | 2 079 | 1 972 | 2 003 | 2 081 |
| Other WA | 838 | 88 | 33 | 23 | 54 | 30- | |
| Total | 20 056 | 20 299 | 20 078 | 19 634 | 21 177 | 20 121 | 20 793 |

Source: Tourism Research Australia.

Ocean temperature and acidification

Increasing ocean temperature poses a major threat to marine environments along Western Australia's coast, which are major drawcards for tourists. For example, the Ningaloo Coast is identified as one of the State's major natural attractions and potential tourism growth areas. Expenditure linked to dolphin tourists at Monkey Mia is estimated to make up between five and 11 per cent of the total regional economy in the Gascoyne (Stoekl *et al.* 2005). Areas such as Exmouth (whale sharks) and Albany (whales) are highly dependant on specific wildlife populations at certain times of the year and the communities of Rockingham and Bunbury are developing thriving tourist industries around their resident dolphin populations.

Coral bleaching events on the Great Barrier Reef indicate the threat rising ocean temperatures could have on coral ecosystems at Ningaloo. There may also be changes to the Leeuwin Current, which could have major impacts on marine environments along the South West coastline and the animals that live there. This in turn will impact on the tourism businesses which rely on tourist attracted to the marine wildlife.

Adaptive responses

Coastal planning

In 2003 the State Government introduced a Coastal Planning Policy (Western Australian Planning Commission, 2003) including planning guidelines for setback policies for coastal developments. The policy specifically addressed the need to account for the impacts of rising sea levels and extreme weather events on human activities close to the coast.

The policy provides guidance to planning authorities on appropriate setback guidelines based on a 100 year planning time frame. As tourism has such a significant coastal focus in Western Australia, coastal planning issues have major implications for the industry and the infrastructure which has and will be built within the coastal zone in the coming years.

The CRC for Sustainable Tourism is currently researching the impact of climate change for coastal zone management and tourism. The project will provide the base-line for improved risk management of tourists and tourism assets in the coastal zone. Findings are due at the end of 2006 (Specht, 2005).

It may be necessary to continue research and monitoring to ascertain whether planning models provide adequate setback provisions, and if investment is required to protect or upgrade existing infrastructure through mitigation measures or strengthened building codes.

Tourism authority initiatives

The Federal Government's regional tourism funding schemes have in recent years had a specific focus on providing assistance to tourist destinations impacted by natural events such as drought and bushfire (Ausindustry, 2003).

Tourism Western Australia recently commissioned a scenario planning project which will consider major issues affecting tourism during the next 20 years. Climate change and its impact on natural attractions and natural resources is one of the items on the agenda (ACIL Tasman, 2005).

Tourism industry initiatives

In recent years the tourism industry has begun to embrace the concept of accreditation to raise quality standards. This has been in response to environmental management issues generally, but is now starting to consider climate change.

Ecotourism Australia has been at the forefront of developing environmental accreditation standards to increase adoption of sustainable operational practices. In 2004 the Tourism Council of Western Australia in conjunction with Tourism Western Australia also developed an environmental module for the popular National Tourism Accreditation Program. In the same year the Department of Environment and Conservation integrated environmental accreditation into requirements for certain tourism operational licenses.

Adoption of environmental accreditation in the Western Australian tourist industry is still relatively low. Currently 13 businesses have been certified under the National Tourism Accreditation Program's Advanced Environmental Module, and 29 businesses have obtained accreditation under the Ecotourism Australia Eco-certification program. This equates to one per cent of all tourism businesses in the State.

Industry awareness programs need to be funded to encourage greater environmental responsibility and to convince industry of the business argument for adoption of sustainable business practices. Consumer awareness programs are also required to educate the travelling public and ensure adoption of sustainable practices is demanded by people visiting Western Australia. These should include consideration of climate change issues.

Potential mitigation responses

Carbon taxes

There has been considerable discussion about the need to introduce carbon-based taxes as a way of reducing carbon dioxide emissions. While not currently on the agenda, future climate change policies may see the introduction of such taxes.

Carbon taxes will likely increase the cost of airline flights and the cost of petrol. This will impact on the types of visitors Western Australia is able to attract, with price sensitive visitor groups likely to be affected. Depending on the size of cost increases, some international and interstate visitors may choose other destinations, while on the other hand high transportation costs may see more Western Australians holidaying closer to home.

Visitors who are less price sensitive are still likely to travel to Western Australia, particularly if the quality of the visitor experience is maintained. This could then increase the overall yield, or level of visitor expenditure of each visitor to the State.

The Sustainable Tourism CRC is currently undertaking research on the impact of rising fuel prices on domestic and international tourism to Australia. Initial research indicates that the current high fuel prices are having a significant impact on domestic tourism numbers. Further research may be required in the Western Australian context to understand the impacts of rising fuel costs on destinations throughout the State.

Carbon sequestration

If Australia engages in international efforts to reduce greenhouse emissions, the opportunities for Western Australia to play a major part in the international carbon trading regime may see more land set aside for conservation or forestry areas. The opportunity exists to link these developments with areas which may also be of use for tourism activities, particularly where it is linked to biodiversity conservation and other activities with high tourism appeal.

Research should be considered to identify where these opportunities exist and how carbon sequestration programs could be developed to benefit future tourism development opportunities in SWWA.

Inter-sectoral issues

The competition for scarce natural resources in an environment impacted by climate change may have a significant impact on tourism in the South West. In particular there is the potential for increasing competition between tourism and other interests in relation to water availability.

The Water Corporation is currently considering protection of additional water catchment areas which may quarantine significant natural areas that are the focus for current tourism activity or have tourism development potential. Furthermore, the Department of Water is

developing water resource management plans for a number of rivers and streams in the South West including Lefroy Brook, which is a significant tourism resource for visitation to Pemberton.

The future

Tourism is a major employer and generator of economic wealth in Western Australia, particularly in remote regional areas. Climate change has the potential to have a major impact particularly where it affects the natural attractions and tourism infrastructure that a destination relies on, or affects the price of travelling to, and around, the destination.

The tourism industry has been slow to embrace sustainable business practices and consider the long term impacts of climate change. More research is required to understand climate change and prepare the tourism industry in the South West to address the impacts likely to influence it in the years ahead.

SPORT AND RECREATION

Recorded impacts

Planners and decision-makers in the sporting and recreational sectors have begun to observe climate change impacts in recent years. Reduced rainfall has adversely affected grassed sporting facilities, particularly in regional areas, storms have damaged sporting infrastructure, and increased temperatures are changing the way in which people recreate and the times when they recreate. Given these recent observations and the substantial infrastructure investments that are made in SWWA in sporting and recreational facilities, this sector is becoming especially interested in assessing future vulnerability to climate change. This is also a particularly important area for local governments in the region.

While some impacts on this sector during the past 30 years can be identified as being related to climate change, generally this section deals with future anticipated impacts based on more recent observations and awareness of the issue.

Sporting facilities



The rainfall reductions experienced by SWWA have far-reaching impacts and the impact this has on sporting grounds for example is a marked demonstration of the way in which climate changes can affect so many aspects of peoples' daily lives. Water shortages are having impacts for both the maintenance of existing grassed playing fields and planning for the development of new ones. A number of sporting grounds in regional areas are suffering as a result of water shortages and in some cases this may be compounded by the effects of rising water tables and salinity in rural towns. Several country shires have been advised by the Water Corporation that they cannot continue to reticulate sporting fields with scheme water because of supply

shortages. They will need to find alternative sources and the Department of Sport and Recreation has been approached to part fund these projects.

In relation to future sporting infrastructure, planners need to give consideration to ongoing reductions in rainfall. There have been considerable improvements in turf management strategies including use of recycled water and development of more drought-resistant grass types. Planners are also looking at the use of synthetic turf as an alternative to playing surfaces that require water. While not within SWWA some examples elsewhere in the State demonstrate techniques that may be useful. For many years the City of Kalgoorlie-Boulder has watered its grassed areas using recycled (grey) water. There are a number of golf courses around the state irrigated by grey water and the Shire of Broome has a major playing fields development project under construction which will also use grey water for reticulation.

Increased ferocity of storms, especially in very recent years has caused damage to sport and recreation facilities both in the built and natural forms. Facilities in the Town of Moora were flooded twice in six months over the past seven years causing considerable damage. Facilities in the Shire of Lake Grace were also extensively damaged during the past year due to excessive flooding.

People



Greater awareness about damage to human skin through sun exposure, which has been amplified by ozone depletion, has radically changed participation patterns and physical activity. For example, schools and sporting clubs now reschedule outdoor sports to either early morning or later in the evening to avoid the 'peak' sun periods of the day.

Observation and perceptions

Community involvement generates a sense of belonging and sense of place. SWWA's residents share a unique lifestyle that supports a number of recreational pursuits and contributes to community development.

People often raise concerns about impacts (including climate impacts) when they affect, or are perceived to affect, their lifestyle. It is thought that during the past 30 years decreased rainfall and increasing temperatures are likely to have:

- impacted on sport and recreation facilities;
- reduced the amenity value of some recreational sites;
- affected people's capacity to recreate; and
- caused adverse health impacts limiting recreation activities.

Sport and recreational planners and decision-makers are concerned that impacts such as rising sea levels, flooding and storm surges may cause accelerated erosion and sediment transport. This in turn will impact on:

- existing sport and recreation facilities;
- planning for future sport and recreation facilities;
- recreational fishing;
- continued participation in water sports and others;
- other associated forms of physical recreation, such as walking, etc.; and
- supporting infrastructure and assets, including jetties, sea walls, boat launching ramps and surf lifesaving clubs.



Awareness in the sport and recreation sector is growing of the potential for increased damage to community property through extreme events such as powerful storms. This is in turn likely to cause rising costs to community sport and recreation clubs and local governments for issues such as maintenance and insurance.

Water shortages and resultant restrictions will have implications for design of new facilities and the future of existing facilities. Additionally ongoing water shortages will require review of current irrigation practices, maintenance regimes (including appropriate training and machinery), and the appropriateness of plant and turf species used throughout the region.

As with the health and tourism sectors, the sport and recreation sector is especially keen to better understand the type of demographic changes that might be driven by climate change.

These changes have the capacity to affect sporting participation rates and competition formats, including existing competition structures.

Projected temperature increases may result in greater numbers of people living large distances from their workplace. It is possible that people working in hot inland locations will prefer to live adjacent to the coast and opt for fly-in-fly-out working arrangements. This type of lifestyle presents particular challenges for regional communities, including for traditional sport and recreation volunteer structures and community development.

Responses

Currently some government agencies are reconsidering their investment policies and strategies in relation to the type of sport and recreation facilities that should be built in certain areas. For example, facilities proposed for areas likely to experience major demographic shifts may be designed so they can be transported elsewhere when populations decrease. Demographic shifts of this nature are anticipated in regional and remote areas of SWWA where continued decreases in rainfall will combine with several other factors to encourage further rural decline.

In recent years there has been a considerable change in the way sport and recreation facilities are designed, constructed and managed. This is because of considerable re-thinking about the use of traditional energy sources and the need for energy conservation. For example, Challenge Stadium in Mount Claremont uses a geothermal bore system to heat aquatic facilities. The Town of Eaton has designed its new recreation centre with a ground-level ventilation system to maximise natural air flows throughout the complex.

The Government, through the Department of Sport and Recreation, is developing climate-related responses, although they are not exclusively driven by consideration of climate. These include:

- developing a suite of facility management tools that assist in reducing and treating the effects of climate change. For example, *An Asset Management Guide for Sport and Recreation Facilities* and *The Life Cycle Cost Guidelines for Sport and Recreation Facilities*;
- making a commitment to assist in developing geothermal heating systems for a number of major aquatic centre redevelopments. The Bicton water polo facility received a grant to develop a geothermal heating system as did the Town of Claremont for the redevelopment of its swimming pool; and
- featuring climate change in the program of the Department of Sport and Recreation's 'Active 2006' conference, which included representatives from sports and recreation associations, local government and other industry stakeholders.

The future

Human physical thresholds for temperature and solar exposure during competition have and will continue to change. Further encroachment on these physical thresholds will change the way in which, and timing of when, people play sport and recreate.

Thresholds are now being reached regarding the use of scheme water for irrigating playing fields. An assessment of the impact of this on popular sport and recreational facilities, and the subsequent health and lifestyle impacts is needed.

Access to water for recreational purposes is also reaching a threshold. Seven of the 10 significant rivers between Perth and Bunbury have been lost to the community for sport and recreational use as a result of dam construction. The ongoing impact of climate change may enhance this trend.

During the past 30 years there has been a continuing population decline in rural areas and climate change is likely to compound and perhaps even hasten this trend. This urban drift will be a catalyst for reducing traditional sport and recreation opportunities and activities in these areas, and in turn increase the need for providing community infrastructure in the greater Perth metropolitan area. If and when this trend will stabilise is an important consideration for a number of sectors including sport and recreation. In fact all human service-related sectors will be affected by this trend.

As well as incremental changes in rainfall, temperature and sea level, research is required on the impact of widespread and extreme events on people's lifestyles, including their participation in sport and recreation. For example, what will be the impact from severe water restrictions, storm surges and events such as bushfires?

SETTLEMENTS AND INFRASTRUCTURE

Housing and works

The focus for this section is on changes in:

- building codes and regulation during the last 30 years related to key weather events; and
- design or construction practices that may have occurred as a consequence of either a key weather event or ongoing climate change. A key weather event is defined as one resulting in significant damage to buildings such as severe storms, cyclones and flooding.

This section considers urban planning issues separately under infrastructure. Policy and regulation in this area is integral to facilitating adaptation strategies in buildings, particularly for maximising opportunities for passive-solar designed housing in land developments⁶.

The Department of Housing and Works (DHW) does not have a library or catalogue system so it has been difficult to locate relevant documents on policy or practices during the last 30 to 40 years. Consequently much of this section relies on corporate memory of long serving DHW staff⁷.

Weather events affecting housing and works

A 2005 Geoscience Australia publication '*Natural hazard risk in Perth*' provides some useful context to this section. The report estimates the impact on Perth from the sudden onset of natural hazards, based in part on analysis of historical events as well as developing a number of risk assessment models.

Perth's natural hazard history includes earthquakes, tropical cyclones, cool-season storms, thunderstorms, bushfires, and riverine and flash floods. In spite of the wide range of natural hazards, no single event in Perth or the South West has caused more than five fatalities or \$100 million in insured losses. Consequently, the report concludes 'the citizens of Perth and its hinterland would appear to live in a comparatively benign environment' (Jones, Middelmann and Corby, 2005, p. 4). However, the report does suggest some future vulnerability to the impact of climate change, primarily through sea level rise, particularly between Bunbury and Mandurah (Geoscience Australia, 2005).

⁶ The Western Australian Planning Commission is looking at ensuring that the majority of lots in new land subdivisions have solar access, through instruments such as the R Codes. The Sustainable Energy Development Office is also considering the possibility of developing a rating system for lots to encourage the provision of solar access for housing (personal communication with Neville Peterkin, Program Officer Buildings SEDO, 2 December 2005).

⁷ Amongst others we interviewed the Manager of the Building Codes and Regulation Branch, officers in the Housing and Facilities Management area, and Public Works Strategy.

Wind

Extreme wind is a major hazard experienced in Perth, usually as a result of cool-season storms. Strong fronts cause winds of gale-force intensity near the coast, and may also spawn severe localised winds including tornadoes, which can unroof houses.

An event on 23 May 1994 ranks as one of the most significant cool-season wind storms experienced in Perth, causing an estimated \$37 million in damage. Several houses were completely unroofed although the majority of property damage was only minor. The second most costly event occurred on 16 May 2005 when a cool-season storm caused estimated losses of \$24 million, damaging fences and gates, roofs and walls from cyclonic winds and heavy rain (Jones, Middelmann and Corby, 2005, p. 7).

The report notes inadequate understanding of future severe wind impacts by emergency managers, planners and others. Interestingly, during the community consultation component of this study a number of people at coastal locations noted changes to local wind conditions during the past 30 years. The Australian wind loadings standard places Perth in Region A1—the lowest hazard region⁸. However, this is based on historical data from a weather station at Perth Airport, some 20 km inland. The strongest regional winds, on average, arrive from the west and reduce in intensity as they travel inland. Modelling undertaken for the geoscience report demonstrates that exposed locations close to the coast can experience wind speeds in excess of the Australian wind loadings standard. The report further notes many of the localities that suffered damage in May 2005 were in identified exposed areas. There would appear to be a need to map wind intensity across Perth (and possibly the broader South West region).



Tropical cyclones are infrequent in SWWA, but historically they have been the most significant weather hazard. The single greatest meteorological event was caused by Cyclone Alby on 4 April 1978 when total damage was estimated at \$39 million. Strong winds damaged properties and fanned bushfires, while a storm surge and large waves caused massive coastal erosion and flooding in low-lying areas from Perth to Busselton. It should be noted that while property damage was widespread, it was mostly minor.

Flood

The last major floods on the Swan River were in 1963 and 1964. The Collie River also overflowed in 1963 and 1964, flooding the town of Collie, with evidence suggesting this may have been exacerbated by catchment clearing (Lund and Martin, 2005). More recently parts of the Midwest, wheatbelt and Great Southern have experienced a number of flooding events. Some of this appears to be the result of summer rainfall, something reported frequently during community consultation sessions. Increased incidence of summer rainfall events is considered to be related to climate changes experienced by SWWA, and is anticipated to increase in the future.

⁸ Australian/New Zealand Standard 1170.2:2002 'Structural Design Actions, Part 2: Wind Actions'.

Winter storms can cause tidal surges resulting in flooding in low-lying coastal areas such as Mandurah, Bunbury and Busselton, all of which may be at risk from increased tidal surges caused by sea level rise. Tidal surges can also affect river levels further upstream. For example, on 16 May 2003 a tidal surge caused the Swan River to overflow onto Riverside Drive near the city centre.

Bushfires



Whether due to natural causes (such as lightning strike) or as a result of being deliberately lit, the intensity and rate of spread of bushfires are related to meteorological conditions. Days of high temperatures, low humidity and strong winds are particularly conducive to the spread of bushfires. With a drying climate, increased number of hot days in SWWA and a boom in housing developments in areas at risk of bushfires, this is an issue of increasing concern.

Perth's most susceptible locations to bushfires are the forest areas in the hills suburbs. On 8 January 1997, bushfires at Wooroloo and Wundowie destroyed 16 homes and part of the Wooroloo Prison Farm. Six homes in Perth's northern suburbs were damaged by bushfire in February 2001. On 24 January 1961, a fire front burned through Dwellingup, destroying 132 homes and a number of other buildings. Fortunately there were no human casualties.

The Building Code of Australia (BCA) incorporates the Australian Standard (AS) 3959 'Construction of Buildings in Bushfire-Prone Areas' as a referenced standard—but only specifically requires Class 1, 2 and 3 buildings (residential buildings, motels, apartments and similar buildings) to be constructed in accordance with AS 3959.

The BCA defines a 'designated bushfire prone area' as land designated under a power in legislation as being subject, or likely to be subject, to bushfires. However, unless the State or local government designates bushfire-prone areas, the standards are not enforceable. In March 2005, the Department of Housing and Works published a discussion paper on this issue recommending amendment to the *Building Regulations 1989* to designate all areas as bushfire prone unless identified by local government as being a low bushfire risk. This may go some way to reducing the impact of increased bushfire risk, if indeed there is an increased risk.

Building code and regulations

The BCA is a performance-based code, outlining the technical provisions that buildings and other structures must satisfy. The provisions cover, among other things, structure, fire resistance of building elements and materials, access and egress, services and equipment, health and amenity. It references a number of Standards, mostly Australian Standards, as acceptable construction manuals. The compliance of a building with an acceptable construction manual is deemed as compliance with the relevant Performance Requirement of the BCA.

Wind

It is generally acknowledged that Australia's wind engineering building codes are among the most stringent in the world. The significant event that triggered this response was the damage caused to the city of Darwin by Cyclone Tracy in 1974.

The State's experience as a result of Cyclone Vance in 1999 clearly demonstrates that when housing is constructed according to the Building Code and Australian standards, it is able to withstand severe winds. Usually these standards are only applied to cyclone prone areas but the Department of Housing and Works' response after Cyclone Vance was to enforce this standard throughout the State.

Current standards also include a number of site exposure multipliers regarding terrain, height, shielding and topography. These are intended to identify sites where wind speed is in excess of the standards, thereby requiring a higher standard of building construction.

It is unclear whether all local councils in Perth and throughout SWWA are applying these multipliers and enforcing these standards. It would be fair to say that if the Australian Building Code and standards were enforced throughout the State, buildings would be more likely to withstand severe wind damage. This would include damage resulting from increasingly powerful cyclones, which is expected to be an outcome of climate change.

Energy efficiency

In recent times the State has moved to increase energy efficiency measures in relation to the BCA. For example, on 1 May 2006, the BCA was amended to extend the energy efficiency provisions to all classes of buildings, including commercial and public buildings. Previously, these provisions were only relevant to residential houses. At the same time the minimum energy efficiency provisions for new housing were also increased from a minimum four star rating to a minimum five star rating.

This builds on previous efforts where Western Australia adopted BCA amendments in July 2003 to include minimum energy efficiency standards for all new single residential dwellings. In May 2005, the energy efficiency provisions were extended to Class 2, 3 and 4 buildings (multi residential, hotels/motels and residential in a mixed use building).

These energy efficiency provisions in the BCA are a response to the need to reduce Australia's greenhouse gas emissions and were prompted by the development of the Kyoto Protocol. The provisions are therefore not a direct response to any climate related event in Australia, but are related to global climate change more broadly.

Thermal comfort

Temperatures for SWWA are known to have increased by about 0.8°C during the last century. This may have had implications for human comfort during that time. Appendix Five of the BCA shows Australian Bureau of Statistics information on dwellings in Western Australia with air conditioners and insulation between 1994 and 2005. In summary:

- in 2005, almost 70 per cent of dwellings had air conditioners. This is a significant increase from 35 per cent of dwellings in 1994; and
- almost 65 per cent of dwellings have insulation in 2005, compared to 52 per cent in 1994.

However, it is difficult to make a direct correlation between this statistical data and climate issues. It is more likely that the large increase in air conditioning use is because of the availability of cheaper, energy-efficient, reverse cycle air conditioners (which can also be used for heating), and people's increased expectations about thermal comfort.

The increasing percentage of dwellings with insulation could be due to the fact that new houses are required to have at least roof insulation under the BCA's energy efficiency measures.

Planning and infrastructure

This section focuses on how the planning and infrastructure sector (with a focus on land use planning related to buildings and settlements) has responded to, or been aware of, climate change during the past 30 to 40 years.

The State's Planning and Infrastructure portfolio combines planning, lands, transport and roads, and currently includes three State government departments, eight port authorities, five development authorities and the Pastoral Lands Board. The Department for Planning and Infrastructure (DPI) is responsible for planning policy and transport infrastructure in Western Australia.

Land use planning and climate change

The processes contributing to the enhanced greenhouse effect that the planning sector can influence and/or minimise fit broadly within two categories:

1. **Reducing emissions:** Transport is recognised as the fastest growing sector for greenhouse gas emissions (Western Australian Greenhouse Strategy, 2004). Land use planning can have a long-term effect on emissions by influencing and altering the design of urban environments so that distances travelled are reduced, encouraging the use of alternate modes of transport (to the car), and ensuring transport systems are better integrated with the design of urban settlements.
2. **Adaptation:** Land use planning needs to consider the impact of increased risks and intensities of floods, storm surges and rising sea levels when planning settled areas. As temperatures rise and evaporation increases, the protection of existing drinking water resources also need to be considered in planning decisions.

The Department for Planning and Infrastructure already contributes to mitigating the effects and impacts of the enhanced greenhouse effect and climate change. For example, the 'Liveable Neighbourhoods Community Design Code' promotes innovation in overcoming car dependence while the 'TravelSmart Household' campaign promotes the use of public transport, cycling and walking.

Climate change and planning—influence of greenhouse

In establishing the National Climate Change Adaptation Program, the Australian Government has recognised that a coordinated approach is needed to developing adaptation strategies to prepare and cater for the implications associated with climate change.

At a State level, the *'Report to the Western Australian Greenhouse Council by the Transport, Urban Land Use and Planning Working Group'* (For Public Comment, June 1999) examined in detail the context of land use planning with respect to its contribution to greenhouse gas

emissions and recommended abatement strategies. This work was taken further, culminating in finalisation of Section 2.4 (Land Use Planning and Transport) of the State Greenhouse Strategy.

In May 2001 TransScan (a quarterly journal providing an international scan of emerging trends in mobility and the built environment, published by DPI and Main Roads Western Australia) published an article titled *Climate change will pose greater uncertainty for urban planners*. It was a discussion paper highlighting the IPCC's assessment for potentially unprecedented costs from damage to coastal infrastructure as a result of extreme weather events, in spite of increased efforts to fortify infrastructure and enhance disaster preparedness. Of importance to the planning sector is that the IPCC notes that '*part of the observed upward trend in disaster losses is linked to socio-economic factors, such as population growth, increased wealth and urbanisation in vulnerable areas*', and not just the severity of the weather (TransScan, 2001).

Further work with particular emphasis on development assessment has been done recently at the international level. In particular a report issued by the Three Regions Climate Change Group comprising representatives from the East of England Sustainable Development Roundtable, London Climate Change Partnership and South East Climate Change Partnership titled *Adapting to Climate Change: A Checklist for Development* (November 2005). It was drafted to prompt discussion on various guidance notes produced for designing developments in a changing climate. The suggested checklist looks at location and layout of developments, building fabric (structure, envelope and materials), ventilation and cooling aspects, other infrastructure (drainage, water efficiency and outdoor spaces) and services (water services and infrastructure resilience).

Coastal planning

National and State forums are addressing the growing concerns about coastal planning and climate change. An increasing number of policies are being developed. The Coast to Coast 2002 Conference in Tweed Heads Australia looked at many of the issues, with the report *Climate Change and Coastal Response* (Coastal CRC, April 2004) being a key output. Another example included the *Framework for a National Cooperative Approach to Integrated Coastal Zone Management* (Natural Resource Ministerial Council, October 2003) conference. The State's coastal planning fraternity has also been actively involved in developing adaptation strategies with respect to climate change. For example, a key issue at the 2005 Coastal Conference in Busselton was the need to push set backs for coastal developments toward 50 metres.

The *State Coastal Planning Policy Statement of Planning Policy No. 2.6* (WAPC, 2003) takes into account the need to ensure that buildings on the coast are positioned to avoid the risk of damage from sea level rise, shoreline movement and severe storms, and to ensure that there is sufficient planning to allow for biodiversity conservation and coastal recreational use. Where possible, there should be no need for physical structures to protect development from potential damage caused by physical processes on the coast.

Planning responses to climate change

When assessing the planning portfolios' responses to climate change during the past 30 years, it becomes evident that climate change issues became more prevalent and easily identifiable in the past five to 10 years. Since then general awareness of the issue has been heightened, and the sector's policies, strategies and projects display more direct relationships to adapting to climate change.

A more liberal and open-ended definition of climate change is needed when extending the focus beyond 10 years to link the sector's actions to global climate change. There are certainly instances where policies or decisions can be seen to be of benefit given our current understanding of climate change. However, they were not direct responses to, or even acknowledgment of, the climate changes that we now know have affected SWWA.

Having said this, a number of policies and strategies do have some relationship to, and implications for climate change responses. As most planning policy with respect to climate change is developed at the national or State level, most of the initiatives outlined below are Statewide and not specific to SWWA. A glance at some examples indicates the extent to which climate change is acknowledged as a planning issue as well as the policies and procedures it may influence in the future.

Development Control Policy 6.1 Country Coastal Planning Policy (State Planning Commission (SPC), June 1989; under review August 1999)

This policy deals with coastal erosion problems, although it notes the scientific prediction for an increase in atmospheric temperature in relation to the enhanced greenhouse effect. It states that 'State departments will monitor such changes and will take whatever action is necessary'.

Development Control Policy 3.4 Rural Land Use Planning (superseded)/Planning for Better Bush Fire Protection (SPC, June 1989)

These policies and guidelines provide fire protection measures for all developments which have the potential to be exposed to bushfires. They do not acknowledge an increased risk of bushfires due to climate change. The policies were developed because of the increase in rural subdivisions and urban expansion. They were superseded by new a Development Control Policy and Guidelines in 2001 (see below).

Development Control Policy 6.3 Planning Considerations in the Metropolitan Region for Sources of Public Water Supply and Sensitive Water Resource Areas (SPC, August 1989)

This policy statement reflects the growing awareness within the community that water is a scarce resource and needs to be managed with care. It was adopted by the State Planning Commission following development of a draft policy on Water Sensitive Residential Development. However, there are no acknowledgments that attribute climate change with encouraging their development.

Residential Planning Codes Statement of Planning Policy No. 1 (WAPC, 1991)

The Residential Planning Codes have been operational since 1985 and deal with fundamental aspects of residential design. The intent of the codes is 'to fulfil objectives of urban containment by encouraging a wider range of lot sizes and an increased variety of housing types throughout residential areas'. They encourage environmentally sensitive design and provide general guidelines and principles for climate-sensitive design (limiting energy consumption, optimising on-site solar access and protecting solar access from neighbouring properties). Updated Codes were released for public comment in October 2000 (see below).

Land Use and Water Management Strategies (Various; WAPC, 1995-current)

Again perhaps supplementary to the climate change debate, the WAPC has recognised the scarce water supply for Perth and declining rainfall. It has prepared various land use and water management strategies. The aim of these is to ensure that land use in the vicinity of selected public water supply areas is managed to protect the quality of the supply and to reduce the risks of contamination.

Implemented strategies exist for Jandakot underground water mound (1995) and Gnangara underground water mound (2001). A draft strategy has also been developed for the Middle Helena Catchment Area (2003) focussing on land surrounding the pump-back dam supplying water to Lake C. Y. O'Connor (public drinking water source for Perth and the Goldfields) and recently the East Wanneroo groundwater area (2005).

Development Control Policy 3.7 Fire Planning (WAPC, October 2001)/***Planning for Bushfire Prevention*** (WAPC and FESA, December 2001)

The focus of this policy is bushfire protection within new land developments. This is done through strategic land use planning, good subdivisional layout and the development of criteria to ensure the least possible exposure to damage by fire and the best possible response should fire occur. The document also provides a benchmark for bushfire prevention planning within existing communities. These are based on experience and research of fire events within Western Australia and interstate. However, they were not developed in direct recognition of changes to climate, or the frequency or intensity of bushfires.

Public Drinking Water Source Statement of Planning Policy No. 2.7 (WAPC, June 2003)

This policy addresses land use and development in public drinking water supply areas at a State level. It uses similar methodology to that used in Land Use and Water Management Strategies (see above).

Framework for a National Cooperative Approach to Integrated Coastal Zone Management—DRAFT IMPLEMENTATION PLAN (Natural Resource Management Ministerial Council, November 2004)

This national draft implementation plan highlights climate change as Priority Area Three (out of a total of six Priority Areas) and identifies vulnerabilities and risks. The draft has actions assigned to various national bodies (mainly government) over a two to 10 year timeframe. The main objectives identified are to:

- improve understanding of the impacts of climate change on the coastal zone; and
- develop strategies to effectively identify and manage climate change threats and opportunities within the coastal zone.

This last objective will be achieved through developing guidelines and tools for coastal zone managers and planners on climate change risks, liability and adaptation options and 'share' the outcomes.

BASIX (DPI/WAPC)

The Sustainability Unit of DPI is currently developing a BASIX development sustainability assessment scorecard, based on the NSW Government tool of the same name. Essentially it is an on-line demand management and regulatory tool which sets targets for energy and water consumption reductions within the built fabric of structures. The targets are set against benchmark levels of consumption in similar existing housing stock.

It will be web-based, simple and free to use and is currently in its design, consultation and testing stage. It is anticipated to be operational in Western Australia within 12 months. Based on results from NSW implementation of a BASIX system, reductions are expected to be in the order of 25 per cent for water and 40 per cent for energy.

Natural Hazards and Disasters Statement of Planning Policy No. 3.4 (Draft September 2004)

In September 2004, the WAPC released a draft Section 5AA policy that applies to the planning and development of land that may be affected by natural disasters and hazards. It aligns previous policy, including the Emergency Management Australia manual, Planning Safer Communities (2002) and bush fire policies and uses a model for emergency risk management in the context of floods, bush fire, landslides, earthquakes, cyclonic activity, severe storms, storm surge and coastal erosion. The SPP is expected to be finalised in the first half of 2006.

Local government

The Department of Local Government and Regional Development has responsibility for local government in Western Australia. However, local governments' responsibilities centre more on administration of planning codes that are the responsibility of the DPI as highlighted above. Local governments work with the community and businesses and are responsible for planning, constructing, operating, maintaining and regulating economic and social infrastructure, overseeing planning and development processes, and setting local environmental policies.

The Western Australian Local Government Association (WALGA) is the peak organisation of local government and is committed to assisting local government authorities in achieving sustainability goals. On 30 January 2003 WALGA provided a major submission to the State Government supporting the State's sustainability agenda and its Greenhouse Strategy.

More importantly WALGA has worked actively to bring projects into reality supporting member councils and initiatives such as the:

Cities for Climate Protection (CCP) Campaign

Twenty eight member councils representing 67 per cent of the State's population are currently involved in the program at various stages. Twenty-seven have already completed an inventory and forecast of key sources of greenhouse emissions with almost 50 per cent of these to achieve up to 30 per cent reductions by 2030.

Street Lighting Group

A subset of CCP, it was determined that street lighting was the largest component of energy use for local government (a responsibility of local rather than State Government in Western Australia). Western Power and local government are now considering this arrangement and issues related to it.

Sustainable Development Advisory Group

This group was established in 1997 (formerly the Local Agenda 21 Group). WALGA coordinates and supports the Group. Its achievements include the development and publication of the Local Agenda 21 Report Card (collection of studies of Western Australian Councils undertaking Local Agenda 21 activities).

Coastal Management Group

This group was established in 1995. Its key objective is to facilitate outcomes to strategic policy initiatives for sustainable coasts management and the Group has been important in many planning forums and deliberations in the State.

WALGA particularly recognises the need for more activity in the area including relevant climate change information and resources to support member councils in coordinated action.

ELECTRICITY

While a case could be made that climate variability and change has altered consumer electricity demand during the past 30 years, links between the electricity generation sector and climate change have only been recognised more recently. This is largely in response to the role the electricity generation sector can play in mitigating greenhouse gas emissions, rather than in developing adaptation strategies.



Electricity demand

Historically, electricity demand has increased at about three per cent directly correlated with population growth for SWWA. However, peak electricity demand has increased geometrically against population growth with the summer peak now much higher than the winter one. The high daily load in summer is also over a longer period than in winter, usually extending from late morning until mid evening on hot days. It is further accentuated by new demands such as swimming pool pumps and split-system air-conditioners, which are now cheaper to buy, easier to install and cheaper to run. Additionally, the move towards 'standby' modes that are never turned off on electrical items such as televisions and computers has increased electricity demand at a rate exceeding population growth.

Responses to greenhouse

Carbon intensity (tonnes greenhouse gas per unit electricity supplied) has decreased progressively for many years. It can be argued however, that this is more likely a function of good management and improved technology, rather than adaptation to climate change.

Emission reductions

Western Power operated as a vertically integrated electricity generating, distributing and retailing company until 31 March 2006, after which it was split into four companies:

- Verve Energy, which generates into the South West Integrated System (SWIS);
- Western Power, which owns and operates the SWIS;
- Synergy, which retails on the SWIS; and
- Horizon Power, which generates, distributes and retails in areas off the SWIS.

Since it began, Western Power Corporation and its successor corporations have sought to achieve environmental excellence and lead development of sustainable energy resources. Greenhouse gas mitigation has been an issue in Western Australia since the early 1990s and was taken up by Western Power in 1997, when it voluntarily committed to the Australian Greenhouse Office's Greenhouse Challenge Project. Western Power has since planted more than four million trees to offset its greenhouse gas emissions through the Western Power Greening Challenge. This involved the communities of the Hotham-Williams Catchment south-east of Perth and landcare agencies since 1996, where seedlings have been planted on degraded land by more than 5000 Western Power staff and community volunteers.

Verve Energy has an ongoing program of asset replacement as assets reach the end of their economic life, which provides an opportunity to reduce emissions. For example, the Muja A and B power stations will be decommissioned in 2007 and it is planned to replace these

'dirty' plants, which are operating on 1960s technology, with state-of-the-art gas-fired power stations, which will undoubtedly reduce greenhouse gas emissions.

Newgen has been chosen under the Western Power's Power Procurement Program to build a high efficiency combine cycle gas turbine plant at Kwinana. This plant will have approximately half the carbon intensity of a modern coal fired plant.

Western Power's electricity sales increased by 5.3 per cent up to 13,677 gigawatt hours (GWh) in 2004/2005. Direct greenhouse gas emissions associated with the electricity supplied amounted to 12.36 million tonnes of carbon dioxide equivalent (CO₂e). Of this 11.74 million tonnes was emitted directly from Western Power operations and another 0.62 million tonnes the corporation purchased from other entities to on-sell to customers.

In addition, renewable energy generation has offset an estimated 0.072 million tonnes of CO₂e during 2004/2005. Further emissions offsets of 0.13 million tonnes is estimated to have been absorbed by Western Power's tree plantation activities in the same period.

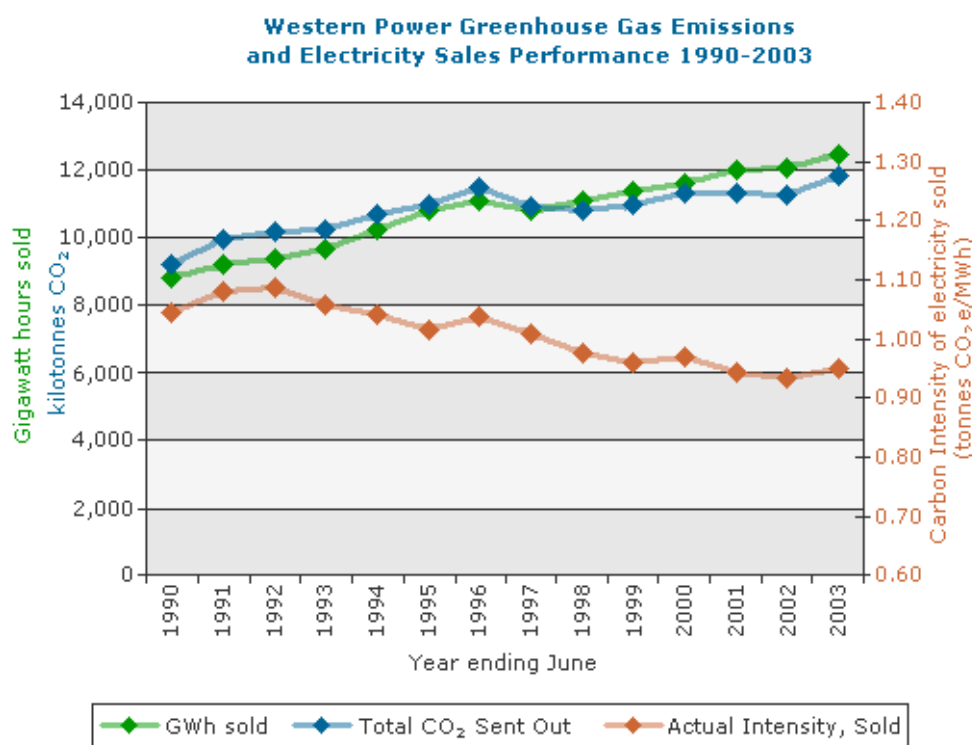
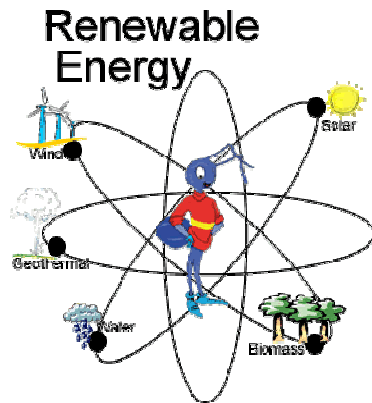


Figure 16 Western Power's Greenhouse Gas Emissions and Electricity Sales Performance, 1990-2003.

Source: Verve Energy, Latest figures for above graph: 2004: 13,536 GWh, 11.76 million tonnes of CO₂e, intensity 0.91, 2005: 13,677 GWh, 12.34 million tonnes of CO₂e, intensity 0.90.

The greenhouse intensity of electricity sold by Western Power decreased marginally in 2003/2004 to 0.91 tonnes CO₂e/MWh. In 2004/2005 greenhouse emissions rose slightly to about 12.34 million tonnes, demonstrating a continuing trend of stabilised emissions in spite of growing supply volumes. This was reflected in a steady decline in the greenhouse intensity to 0.90 tonnes CO₂e/MWh.

Renewable energy



Western Power Corporation and later, Verve Energy has continued to seek opportunities to reduce emissions, with some achievements and future plans including:

- Western Power's 21 MW wind farm at Albany was commissioned in 2001. At the time, it was Australia's largest wind farm.
- In 2004/2005 Western Power generated enough renewable energy from generators including the Albany, Denham, Esperance (Ten Mile LDCCon and Nine Mile Beach), Hopetoun and Exmouth wind farms, to create more than 72,000 renewable energy certificates (RECs). It also sourced 106,000 RECs from other generators.
- A 3.6 MW wind farm at Nine Mile Beach in Esperance commenced operation in July 2003. While initially generating renewable electricity for the Esperance diesel power system, the system converted to natural gas generation at the start of 2004. The wind farm has continued to generate renewable energy and is possibly the only wind farm in the world contributing to a system with a regional gas-fired power station.
- Approximately 25 per cent of Esperance's electricity requirements can be supplied by renewable wind energy from the Nine Mile Beach Wind Farm and the older Ten Mile LDCCon Wind Farm.
- Verve Energy, through its subsidiary Diesel and Wind Systems, has installed wind/diesel systems with high wind penetration at Denham, and Bremer Bay. A wind/diesel system is being completed at Hopetoun and a similar system is being installed at Coral Bay. The systems save 1.8 million litres of diesel fuel each year.
- In 2004 and 2005, the Retail Division of Western Power launched two RECs procurement processes to provide an opportunity for local renewable energy generators to supply up to 180,000 RECs per year and the associated energy, for a period of up to 10 years, providing a considerable financial boost to the local renewable energy industry. Relaxed market access arrangements were introduced to support private renewable electricity generators and implemented Network Access arrangements for smaller renewable generators (less than 10 MW in size) reducing the cost of matching generator output to loads supplied by that generator.
- In November 2002, the paper entitled 'Technical and Commercial Issues for the Access of Renewable Generation to the Western Power South-West System' was released assisting access for independent suppliers of renewable energy to enter the market.
- The purchase of RECs associated with the sale of solar hot water heaters has provided flow-on incentives for residential customers who chose solar hot water systems with electric boosters as opposed to solely electric hot water systems.
- In 2006 Verve Energy's demonstration Integrated Wood Processing (bioenergy) Plant in Narrogin was commissioned. The plant converts locally grown mallees into electricity, eucalyptus oil and activated carbon. The project has actively involved the community and Verve Energy is developing a machine for harvesting mallee trees in conjunction with the Oil Mallee Company. The production of activated carbon as one of the products is a key factor to the financial viability of the project. The project is supported by the DCC and AusIndustry and is set to provide a solution for reliable

renewable energy and land degradation in regional areas. Verve Energy is further fostering such activities through Western Carbon Pty Ltd a wholly owned subsidiary formed in 2002.

- Verve Energy monitors developments in solar energy technology. It upgraded its Kalbarri Solar Photovoltaic System with a new sun tracking system during late 2002. The system is currently undergoing trials and aims to improve the output of the facility. Research on the Rockingham Solar Concentrator System has continued and access is being provided to Murdoch University students to further solar research.
- Western Power and Synergy have assisted both of the State's bids (Perth and Kalgoorlie) to the Commonwealth's Solar City Program.
- Two large wind farms were or are being built by the private sector in 2005/06. They are Renewable Power Ventures' 90 MW wind farm at Walkaway and Stanwell-Griffin's 80 MW wind farm at Emu Downs.

The future

While the electricity industry's efforts have been focused on greenhouse gas mitigation in the past, it understands that climate change could drive adaptation responses as a result of impacts on energy demand, energy generation and energy transmission.

- Hotter temperatures will increase the energy demand for cooling and reduce the efficiency of energy generation and transmission.
- More intense storm events will increase the risk of transmission and distribution failures, and also affect accessibility for maintenance and repairs, particularly in remote areas.
- Reduced water availability will affect power generation (water is required for cooling), especially in the Collie Basin.
- Changes in water availability and wind may affect renewable energy generation, including wind-power and bioenergy.
- Longer periods between rainfall events could exacerbate the shorting out (pole-top fires) of dusty transmission lines when rain does occur (Queensland Department of Natural Resources and Mines Climate Smart Adaptation, 2005).

CONCLUSIONS AND FUTURE NEEDS

As a generalisation it would be fair to characterise SWWA's concern about, and commitment to, planning for climate change during the past 30 years as 'emerging'. The study shows that while there are some notable exceptions, most sectors have only begun reacting to climate change within the last five to 10 years. It also shows that past responses to global climate change have predominantly been focused on mitigation rather than adaptation, reflecting past policy direction in relation to climate change nationally and internationally. However, as the inevitability of future climate change becomes clearer and worldwide attention shifts toward adaptation, so too SWWA's sectors are becoming aware of the need to develop adaptation responses.

Key messages

Difficult to perceive past climate changes and impacts but...

A lack of general awareness and action about climate change during the past 30 years was because of a community perception that there was little factual reason to be alert to it. Many organisations did not capture data or undertake specific monitoring that would lead them to conclusions about climate impacts. During this study, several sectors found it difficult to source data that would allow conclusions to be drawn about the impacts of climate change, and had to rely on corporate memory and recollections, and interpreting other 'climate-related' information.

Further masking specific observations is the diverse range of other factors that drive people's planning, decision making and actions. It is often far too simplistic to link a particular trend, such as a growth in purchase of air conditioners, to a feature of climate change—that is, increasing temperature. While with hindsight we might conclude that increasing temperatures played a part in driving this trend, the truth is it's more likely a function of affordability and increasing affluence. However, the study has been useful in identifying the range of factors that may in some way be linked to climate change. The exercise has encouraged more critical analysis of the changes that occurred during the last 30 years within the context of climate change that we now know has occurred and will continue well into the 21st century.

It appears that all sectors (at a decision making level) now seem to accept climate change as a reality. While several have not factored it into past planning, most are committed to assessing its future impacts. For example the State's health, tourism and biodiversity agencies plan to assess future impacts of projected climate change and the agriculture sector is already undertaking some assessments. The Water Corporation will continue to plan for ongoing rainfall reductions and the newly formed Department of Water is undertaking planning aimed at improving institutional arrangements for managing this precious resource, specifying future climate change as one of several issues for management.

Community consultation also reveals increasing awareness of climate change. Farmers acknowledge that their ongoing management of climate variability has effectively masked the impacts of climate change and that at some locations they now need to understand when critical thresholds may be reached. Lifestyle-related sectors have recently become far more aware of the potential impacts of climate change, especially in relation to impacts on sporting and recreational infrastructure. Sports grounds and recreation complexes represent major investments for government and the community, and consequently require careful planning in the face of climate change.

SWWA has coped pretty well so far but...

Given the region's ongoing prosperity and economic development, improved community health and wellbeing, and reasonably healthy environment, SWWA seems to have coped fairly well so far with climate change. This is not necessarily surprising and is similar to other affluent parts of the world where people, organisations and institutions can invest in systems and technologies that allow them to cope with a range of impacts, including the effects of climate change.

However, the extent to which the region's people, industries and environment can continue to cope with climate change is uncertain, and there are some emerging studies suggesting certain sectors display significant vulnerability. For example agriculture and forestry are considered to be vulnerable to ongoing decreases in rainfall at particular locations with local farmers and foresters in areas of the Great Southern indicating they may in fact already be nearing thresholds in terms of being able to maintain optimum productivity. Additionally, studies of crop vulnerability by the Department of Agriculture and Food suggest significant productivity reductions due to declining rainfall and temperature increases in eastern and northern wheatbelt areas.

These observed and perceived future vulnerabilities have led these sectors to invest more heavily in research and planning for climate change. The water utility, agriculture and forestry sectors have all undertaken research within the last 10 to 15 years to better understand the nature and consequences of the region's declining rainfall. On the other hand, sectors such as health, sport and recreation, tourism, and fisheries appear to have done little in the past, with climate change being a relatively low priority in comparison to their core activities. However, these and other sectors are beginning to consider where their major vulnerabilities lie and when they may reach critical thresholds.

Additionally, because climate change is only beginning to be considered by many sectors, its capacity to create conflict has not yet been fully revealed. As sectors begin to plan adaptation strategies to increase coping capacity, it is very likely conflicts will emerge about decisions to implement a particular strategy to protect one resource, asset or industry over another.

Regional SWWA is particularly vulnerable

Regional SWWA is particularly vulnerable to climate change. The industries that support regional communities rely heavily on the State's natural resources (particularly water), which are especially vulnerable to climate change. Agriculture in a number of regional locations displays significant vulnerability to ongoing water shortages; tourism, which is the lifeblood of many regional economies, will be adversely affected by climate change; and sport and recreational activities that are important for community development will be affected.

Community consultation sessions highlighted growing regional concerns about climate change, another pressure facing rural communities already in decline.

Awareness and interest is growing

Awareness of climate change is growing across the board. All sectors are increasingly willing to better understand and plan for the impacts of climate change. It will be important to capitalise on this growing interest and support decision makers, organisations and institutions in developing and prioritising appropriate adaptation responses.

Water is the driver

The climate variable that has predominantly driven awareness of climate change in SWWA is rainfall. Sectors that rely on water or manage water availability have clearly observed and responded to climate change. For the foreseeable future, water will be the major resource impacted by climate change. Throughout this study, water availability was raised as a primary concern by all sectors. Community interest and controversy about water shortages is increasingly covered in the daily media and is growing markedly. While there are a number of other issues that may be of significant concern in the future, such as the increased incidence of heat-related deaths and the impact of storm surges on coastal infrastructure, the water issue is with us now.



It has already been recognised that rainfall levels are declining and consequently the water supply is at risk. Planning by water utilities for future needs is well under way. The Water Corporation and Department of Water are working on a range of initiatives to ensure ongoing supply. Appropriate institutional arrangements are in place to improve water resource management decision-making.

What are the critical issues for the future...?

Organisations have identified a range of activities that may be affected by climate change. It will not be possible to address all of these and it is the responsibility of each organisation to address its specific risks, whether these are posed by climate change, some other threat, or an interaction of risks. However, there are some identified climate changes that will cause cross-organisational impacts which create synergies in preparing for climate change. This reflects the coordinated approach recommended in the National Climate Change Adaptation Framework (2007).

Health, wellbeing and lifestyle

Increasing interest in climate change has come from organisations involved in health, wellbeing and lifestyle. Representatives found that many of their needs in relation to future planning were similar, and there was a strong willingness by government organisations to progress planning for future impacts. These sectors' planning needs are strongly linked to demography and, in the context of this study, the potential for climate change to drive demographic changes, which in turn affect where they target their activities and investment (some of which are substantial).

Phase Two should support bringing these sectors together to assess the impact of climate change on demography.

Productive terrestrial ecosystems

Agriculture and forestry have similar needs in relation to assessing impacts of climate change scenarios. Both industries have thresholds in relation to water availability and temperature, and both display vulnerability to particular events such as drought and widespread frost. However, both may benefit initially from certain elements of climate change such as increased CO₂ and moderate increases in temperature.

In the future there is the potential for increasing competition between agriculture and forestry operations for water resources. Consequently the industries will need to work together to resolve conflicts that arise and develop adaptation strategies that are mutually beneficial.

Both industries are also mainstays of many rural and regional communities. Climate change impacts on these industries will have a significant effect on these rural communities.

Furthermore, both industries may have a role to play in carbon sequestration. There are synergies between agriculture and farm forestry, and there may be systems where sequestration benefits can be optimised.

Natural ecosystems and biodiversity

Biodiversity underpins the wellbeing of all industries and communities. However, to date there is limited understanding of the impact of climate change on the State's biodiversity.

Climate change impacts on ecological systems and biodiversity will initially be subtle but increasingly significant; for example they will include changed fire behaviour, a loss of wetlands, new pests and diseases leading to death of woodlands and the extinction of plant and animal species. These impacts are expected to detrimentally affect water supplies, tourism resources and infrastructure.

Western Australia's lifestyle values, water resources, tourism industries and agriculture production all directly depend on intact ecological systems and landscapes. There are important though less direct links between ecological systems and human health, sport and recreation activities, and infrastructure.

Climate is a fundamental factor in determining where species can survive and reproduce, the types of ecosystems that can develop in an area and the visual landscapes present in a region. When the climate changes, it is inevitable that species, ecosystems and landscapes will be affected.

A better understanding of climate change impacts on biodiversity in SWWA is required. Modelling of future impacts about how the State's ecosystems and landscapes will change is needed to guide actions to effectively protect the State's biodiversity, and in turn the systems that depend on it.

The built environment

There is an increased likelihood of extreme events occurring due to climate change, particularly for coastal locations which are predicted to be subject to sea level rise, stronger winds and storm surges. This is an issue of major concern as more than 90 per cent of SWWA's population is located along its coastline, and housing and infrastructure development along the coast is growing considerably.

This combination of factors presents significant challenges for the State's planning, infrastructure and building sectors, and for local government. As such an assessment of the impact of climate change on the built environment at coastal locations is needed.

A recent article by the Western Australian Sustainable Energy Association (2006) highlighted that a sustained global temperature increase of three degrees above 1990 levels will raise sea levels by seven metres, shifting Perth's coastline 700 m inland. Such a rise is at the upper end of the spectrum, but within the boundaries of future predicted temperature increases. A one metre rise is more likely by the end of the century, which will cause

significant damage to coastal infrastructure and ecology (Knight, 2006). In addition, a report by the Insurance Council of Australia (2006) highlighted Perth as one of the three most vulnerable zones in Australia to coastal flooding, and Rockingham as one of the three most vulnerable local government authorities in the country.

Water resources

Water and biodiversity sustain all industries, communities and healthy ecosystems. Given the inherent need for water by plants, animals, human beings and industries in the region, analysis of increasing demand for water in the face of decreasing supply is recommended.

Debate surrounding the issue of declining water supply and possible responses by the State Government highlights the way in which climate change can generate conflict. There is varying community, industry and political opinion about the merits of investment in new water source development initiatives such as desalination, groundwater extraction and catchment thinning. The potential for conflict is also greater here due to the pervasive nature of the impacts and the extent to which climate so intrinsically affects our daily lives.

Integrated assessment

Phase One of this study has found that, in retrospect, many people can relate their experiences or observations to climate change. However, because they regard climate change to be such an omnipotent force, they conclude that they cannot do much about it, and in any event have more pressing shorter-term imperatives facing them. As a result they adopt a view that government will do something, or they will continue to cope or adapt (or more likely react) when they need to. Consequently, in the interim people tend not to do anything specific but take some *ad-hoc* measures that can in hindsight be rationalised as having had some relationship to climate change.

The challenge for the future is to better understand the range of influences at work in peoples' decision chains such as that described by Senge (1990) for example (**Figure 17**) and develop programs to facilitate a change process that leads to adaptation based on new beliefs about climate change.



Figure 17 Senge's model of decision making.

This can be achieved through disseminating information, and by providing opportunities for people to understand the consequences of different actions, to question their assumptions, conclusions and beliefs, and to encourage them to consider different perspectives, which may alter their observations, filtering and colouring of experiences. The fields of environmental education and extension can assist in the development of techniques to

facilitate this change process, which can be used within the context of the Phase Two 'integrated assessments' of SWWA's vulnerability to climate change.

Integrated assessment can be defined as the interdisciplinary process of integrating knowledge from various disciplines and stakeholder groups in order to evaluate a problem situation from different perspectives and provide support for its solution. It should support policy and decision processes, and help to identify desirable and possible options (Pahl-Wostl, 2004). Public policy issues involving long-range and long-term environmental management are where the roots of integrated assessment can be found. Integrated assessment is used to frame, study and solve issues at various scales and has been developed for acid rain, climate change, land degradation, water and air quality management, forest and fisheries management, and public health. The field of integrated assessment engages stakeholders and scientists, often drawing these from many disciplines (The Integrated Assessment Society n.d.).

A 'structured deliberative process' developed by CSIRO may also provide an important process for use with various stakeholders (Syme *et al.* 2006). It was developed to assist in planning responses to climate change in rural areas but could be adapted for use in Phase two. It is based on the premise that it is important to understand people's decision-making; integrating climate change 'actions' (what people will do to adapt to climate change) and 'impacts' (what people believe are the consequences of those actions) (Syme *et al.* 2006, p. 2).

Recommendations for Phase 2

Following are some specific recommendations for the conduct of Phase Two which closely reflect the *National Climate Change Adaptation Framework* and will contribute to the improvement of adaptive capacity and reduction of vulnerability in the various sectors.

- Key outcomes of Phase 1 were the opportunity for different sectors to discuss climate change together, start to examine synergies and areas of potential conflict, and raise awareness. Phase 2 needs to build on this momentum.
- Ensure better engagement of the health, local government, planning, fishing and tourism sectors, partly to gain more information on the impacts of climate change on these sectors but also to gauge the level of adaptation required.
- Identify any external obstacles to adaptation for different stakeholder groups and, where possible, remove these obstacles.
- Resources need to be allocated to downscaling of regional models.
- Ensure independent information on climate change which is consistent, targeted and relevant. It is important that different sectors don't develop adaptation strategies based on different scenarios for example.
- Provide evidence of the ways in which climate change is impacting on each sector, initially through the issue of water shortages.
- Ensure the specific information needs identified through community consultation are addressed:
 - prediction for temperature increases, including number of extremely hot days;
 - rainfall predictions including seasonal shifts;
 - assessment of water cycle impacts as a result of reduced rainfall;

- predictions of sea level rise;
 - some indication of the likelihood and timing of extreme events; and
 - scenarios based on different sectors.
- These messages are more likely to lead to action if they are personalised, visual where possible, emphasise emotions (e.g. hope, even fear), repeated from different sources, solution-based and adaptation-based. It will be important to pre-test these messages to establish their effectiveness and to conduct on-going evaluation of their impact.

REFERENCES

- Access Economics. 2003. *The Economic Contribution of Tourism to the State of Western Australia*.
- ACIL Tasman. 2005. Output from the 1st meeting with the EMT/CMT of Tourism WA 11 October 2005.
- Anderson, WK, Hamza, MA, Sharma, DL, D'Antuono, MF, Hoyle, FC, Hill, N, Shackley, BJ, Amjad, M and Zaicou-Kunesch, C. 2005. The role of management in yield improvement of the wheat crop—a review with special emphasis on Western Australia, *Australian Journal of Agricultural Research*, 56(11) 1137–1149.
- AusIndustry. 2003. *Regional Tourism Program*, Commonwealth of Australia.
- Australian Bureau of Statistics. 2005. 4602.0 *Environmental Issues: People's Views and Practices*, Commonwealth of Australia.
- Australian Bureau of Statistics. 2005. *Population of Western Australia*, Retrieved 21 October 2005 from www.abs.gov.au.
- Bari, MA *et al.* 2004. *Salinity situation statement Denmark River*. Department of Environment and Conservation, p. 94.
- Bartle, JR and Shea, S. 1989. Development of a pulpwood cropping industry in Western Australia. *Land and Water Research News* 1: 5–9.
- Bartle, JR. 2001. New perennial crops: Mallee eucalypts—a model, large scale perennial crop for the wheatbelt in *Managing Agricultural Resources. Proceedings of Outlook Conference 2001*. ABARE, Canberra.
- Berti, ML, Bari, MA, Charles, SO and Hauck, EJ. 2004. *Climate change, catchment run-off and risks to water supply in the South West of Western Australia*, Government of Western Australia.
- Buckton, M. 2005. *Development of a bioenergy industry in Western Australia*. In: Multiple Benefits from Sustainable Bioenergy Systems. International Energy Agency Bioenergy Tasks 30 and 31 International Workshop. The Vines, Perth.
- Bureau of Meteorology. 2005. *Severe Tropical Cyclone Rosita*, Retrieved 8 December 2005 from www.bom.gov.au.
- Bureau of Meteorology. 2005. *Tropical Cyclones Affecting Perth*. Retrieved 8 December 2005 from www.bom.gov.au.
- Bureau of Meteorology. February 2006. *2005 Annual Climate Summary*, Commonwealth of Australia.
- Butcher, TB. 1986. Rainfall distribution on the northern Swan Coastal Plain, Department of Conservation and Land Management; 1986.
- Carlsen, J and Wood, D. 2004. *Assessment of the economic value of recreation and tourism in Western Australia's national parks, marine parks and forests*, p. vi, Cooperative Research Centre for Sustainable Tourism Monograph.
- Council of Australian Governments. 2007. *National Climate Change Adaptation Framework*, Commonwealth of Australia.
- Coutts, J and Roberts, K. 2003. *Extension Models and Best Practice in Extension*, Invited paper, Australia Pacific Extension Network Forum, Hobart, November 2003.

-
- Department of Agriculture and Food. 2006. *Community, industry and government views on past and future climate change for South West Western Australia*, Technical Bulletin 4706, Government of Western Australia.
- Department of Climate Change. 2005. *Climate Change Risk and Vulnerability*, Report by the Allen Consulting Group, Commonwealth of Australia.
- Department of Climate Change. 2006. *Climate Change Impacts and Risk Management: A Guide for Business and Government*, Commonwealth of Australia.
- Department of Environment and Conservation. 2006. *Western Australian Greenhouse Strategy Annual Progress Report 2005*, Government of Western Australia.
- Department of Health. 2003. *A healthy future for Western Australians, Report of the Health Reform Committee*, Government of Western Australia.
- Department of Health. 2004. *Annual Report*, Government of Western Australia.
- Department of Housing and Works. 2005. Discussion Paper, *Designating Bushfire Prone Areas*. Retrieved 5 December 2005 from http://www.dhw.wa.gov.au/BUSHFIRE_PRONE_AREAS_Discussion_Paper_29-03-05.pdf.
- Department of Industry and Resources. 2003. *Ningaloo Reef Retreat—A Case Study*. Retrieved 8 December 2005 from <http://www.industry.gov.au>.
- Department of Natural Resources and Mines. 2005. *Climate Smart Adaptation: what does climate change mean for you?* Queensland Government.
- Department of Public Health. 1961. *Annual Report*, Government of Western Australia.
- Department of Sport and Recreation. 2004. *Asset Management Guide, Sport and Recreation Facilities*, Government of Western Australia.
- Department of Sport and Recreation. 2005. *Life Cycle Cost Guidelines, Sport and Recreation Facilities*, Government of Western Australia.
- Department of the Premier and Cabinet. 2004. *Western Australian Greenhouse Strategy*, Prepared by the Western Australian Greenhouse Taskforce, Government of Western Australia.
- Department of Transport, Main Roads Western Australia and Department for Planning and Infrastructure. 2001. Climate change will pose greater uncertainties for urban planners, *TransScan: A scan of emerging trends in mobility and the built environment*, Volume 3, Number 1, Government of Western Australia.
- D'Souza, N.K. *et al.* 2002. Effects of farmland revegetation on the quantity and quality of soil organic carbon. In: *Future soils: Managing soil resources to ensure access to markets for future generations*. Perth, Western Australia.
- Eliot, I, Saynor, MJ, Eliot, M, Pfitzner, K, Waterman, P and Woodward, E. 2005 (unpublished). *Assessment and Development of Tools for Assessing the Vulnerability of Wetlands and Rivers to Climate Change in the Gulf of Carpentaria, Australia*, prepared for the Department of Climate Change, Department of Environment and Heritage.
- Environment Australia. 2003. *Climate change impacts on biodiversity in Australia*, Commonwealth of Australia.
- Flannery, T. 2005. *The Weather Makers: The History and Future Impact of Climate Change*, Griffin Press, Melbourne.

- Geoscience Australia. 2005. *Cities Project Perth, Coastal erosion due to long-term sea level rise*. Retrieved 5 December 2005 from http://www.ga.gov.au/urban/projects/nrap/perth_erosion0405.jsp.
- Harper, RJ. 1994. Site selection guidelines for *Eucalyptus globulus* plantations in SW Western Australia, Department of Conservation and Land Management, Western Australia; p. 5.
- Harper, RJ. 2002. The Four Aces: overcoming multiple natural resource management issues in Western Australia through the establishment of greenhouse sinks. Perth: Department of Conservation and Land Management.
- Harper, RJ *et al.* 2003. Opportunities for the Western Australian land management sector arising from greenhouse gas abatement, in Report for the Western Australian Greenhouse Taskforce, brief. AGR131Q-02/03. Canberra: Cooperative Research Centre for Greenhouse Accounting; p. 60.
- Harper, RJ, Edwards, JG, McGrath, JF, Reilly, TJ and Ward, SL. 1999. *Performance of Eucalyptus globulus plantations in South-Western Australia in relation to soils and climate*. In *Balancing Productivity and Drought Risk in Blue Gum Plantations*. Karri Valley Resort, Pemberton, Western Australia.
- Harper, RJ and Gilkes, RJ. 2001. Some factors affecting the distribution of carbon in soils of a dryland agricultural system in South-Western Australia. In: Lal, R, Kimble, JM, Follett, RF and Stewart, BA, Editors. *Assessment Methods for Soil Carbon Pools*, p. 577–91, Boca Raton, Florida. Lewis Publishers.
- Harper, RJ, McGrath, JF and Carter, JO. 2002. A pedo-geomorphic approach to predicting drought deaths in *Eucalyptus globulus* (Labill.) plantations. In 17th World Congress of Soil Science. Bangkok, Thailand.
- Harper, RJ, McGrath, JF and Maher, TJ. 1990. *Potential for a pulpwood resource in the Esperance District—Evaluation of the climate and soils and project recommendations*, Department of Conservation and Land Management.
- Harper, RJ, Smettem, KRJ and Bartle, JR. 1998. Blue gums: Soil and climate requirements in Moore, G (ed.) *SOILGUIDE: A handbook for understanding and managing agricultural soils*, Department of Agriculture and Food, p. 285–6.
- Harper, RJ, Smettem, KRJ and Tomlinson, RJ. 2006. Using soil and climatic data to estimate the performance of trees, carbon sequestration and recharge potential at the catchment scale. *Australian Journal of Experimental Agriculture*.
- Housing Industry Association. 2000. *Designed and built to weather the storm*, Video.
- Humphries R, Waite, M, Rogoysky, P, Huxtable, P and Hess, M. 2005. *Moving Towards Carbon Neutrality*, paper delivered at Ozwater 2005.
- Indian Ocean Climate Initiative. September 2002. *Climate variability and change in south west Western Australia*, Government of Western Australia.
- Indian Ocean Climate Initiative. August 2005. *How our rainfall has changed—the south-west*, Climate Note 5/05, Government of Western Australia.
- Indian Ocean Climate Initiative. August 2005. *How our temperatures have changed*, Climate Note 2/05. Government of Western Australia.

-
- Insurance Disaster Response Organisation. 2004. *Major Disaster Event List Since June 1967*. Retrieved 8 December 2005 from <http://www.idro.com.au>.
- Jerrard, S and Philip, M. 2006. 'Fruit and veg tops for now, but down track a worry'. *The West Australian*, June 12, p. 3.
- Jones, T, Middelmann, M and Corby, N. 2005. *Natural hazard risk in Perth, Western Australia*, Geoscience Australia, Commonwealth of Australia.
- Knight, S. *What would Mandurah look like if the sea level rose one metre?* Retrieved 13 December 2006 from <http://www.abc.net.au/perth/stories/s1729593.htm>.
- Leigh, R and Chen, K. 2006. *A National Coastal Vulnerability Study*. Report prepared for the Insurance Council of Australia, Macquarie University.
- Lund, M and Martin, H. 2005. *History of water use in the Perth-Bunbury region*. Retrieved 5 December 2005 from www.ecu.edu.au/chs/cem/research/wetlands_research/history/pbhist.html.
- McGrath, JF, Harper, RJ, Dumbrell, IC and Robinson, N. 2002. *Limitations to plantation and farm forestry productivity in Mediterranean environments* in Australian Forest Growers Conference. Albany, Western Australia.
- McGrath, JF, Ward, D, Jenkins, PJ and Read, B. 1991. Influence of site factors on the productivity and drought susceptibility of *Pinus radiata* in the Blackwood Valley Region of Western Australia. in *Productivity in Perspective*. Third Australian Forest Soils and Nutrition Conference. Melbourne: Forestry Commission of New South Wales, Sydney.
- McMicheal, A, Woodruff, R, Whetton, P, Hennessy, K, Nicholls, N, Hales, S, Woodward, A and Kjellstrom, T. 2002. *Human Health and Climate Change in Oceania: A Risk Assessment*. Commonwealth of Australia.
- Minister for Revenue. 2002. *Joint Communiqué Ministerial Meeting on Public Liability Insurance*.
- Murphy, D, Webb, B, Harper, R and Abbott, L. 2002. Can tree-crops ensure the sustainability of degraded agricultural systems? In: *Future soils: Managing soil resources to ensure access to markets for future generations*. Perth, Western Australia.
- Natural Resource Ministerial Council. October 2003. *Framework for a National Cooperative Approach to Integrated Coastal Zone Management*, Commonwealth of Australia.
- Natural Resource Management Ministerial Council. 2006. *Plan for Collaborative Action Climate Change*, Agenda Item 6A, Annex A, Meeting 10, 21 April 2006, Commonwealth of Australia.
- Pahl-Wostl, C. 2004. *Why do we need a Society for Integrated Assessment*, Retrieved 13 December 2006 from [http://www.tias.uni-osnabrueck.de/publications/Why we need an IA society.pdf](http://www.tias.uni-osnabrueck.de/publications/Why_we_need_an_IA_society.pdf).
- Parslow and Jernakoff (eds). 1992. *Managing Australia's Fisheries Under Threat of Climate Change Impact*, compiled by the CSIRO Division of Fisheries, Department of the Arts, Sport, the Environment and Territories, ISBN 0 644 14100 X.
- Penn, JW, Fletcher, WJ and Head, F (eds). 2005. *State of the Fisheries Report 2003/04*, Department of Fisheries, Government of Western Australia.
- Petchell, L. 2006. 'Parched winter sees rural crisis spread'. *The West Australian*, June 26 p. 18.
- Pittock, B (ed). 2003. *Climate Change: An Australian Guide to the Science and Potential Impacts*, Commonwealth of Australia.
-

- Preston, BL and Jones, RN. 2006. *Climate Change Impacts on Australian and the Benefits of Early Action to Reduce Global Greenhouse Emissions*, Commonwealth Scientific and Industrial Research Organisation.
- Ritson, P and Sochacki, SJ. 2003. Measurement and prediction of biomass and carbon content of *Pinus pinaster* trees in farm forestry plantations, South-Western Australia. *Forest Ecology and Management*; 175: 103–17.
- Ryan B and Hope P (eds). 2005. Indian Ocean Climate Initiative Stage 2: Report of Phase 1 Activity, July 2003 to December 2004. *Establishing the methodological foundations of Stage 2 and updating regional interpretations from global climate modelling*. Government of Western Australia.
- Rottneest Island Authority. 2003. *Annual Report 2002-03*, Government of Western Australia.
- Senge, P. 1990. *The Fifth Discipline: The Art and Practice of the Learning Organisation*, Bantam Doubleday Dell Publishing Group, Inc.
- Schlamadinger, B and Karjalainen, T. 2000. Afforestation, reforestation, and deforestation (ARD) activities. In: Watson, RT et al. (eds). *Land Use, Land-Use Change, and Forestry*, p. 127-79, Cambridge University Press.
- Shea, SR and Bartle, JR. 1988. Restoring nature's balance: the potential for major reforestation of south western Australia. *Landscape* 3: 3–14.
- Sochacki, S, Harper, RJ and Smettem, KRJ. Estimation of biomass production from a short rotation bio-energy system in semi-arid Australia. *Biomass and Bioenergy in review*.
- South East Climate Change Partnership. 2005. *Adapting to Climate Change: A Checklist for Development*, Greater London Authority.
- Specht, Dr A. 2005. *Overview of research project: Climate change and coastal zone management: assessment of risk for tourism*. Retrieved 8 December 2005 from www.crctourism.com.au.
- Sutherst, RW and Maywald, GF. 1985. A computerised system for matching climates in ecology. *Agriculture Ecosystems and Environment* 13: 281–299.
- Steffen, W. 2006. *Stronger Evidence but New Challenges: Climate Change Science 2001–2005*, Commonwealth of Australia.
- Stoekl, N, Smith, A, Newsome, D and Lee, D. 2005. Regional Economic Dependence on Iconic Wildlife Tourism: Case studies of Monkey Mia and Hervey Bay, *The Journal of Tourism Studies*, 16(1), p. 78.
- Syme, GJ, McIntyre, W, Tucker, D and Nancarrow, BE. 2006. *A Deliberative Process to Incorporate Climate Change in Catchment Planning*, CSIRO Land and Water Science Report 36/06.
- The American Heritage Dictionary of the English Language*, Fourth Edition, 2000 by Houghton Mifflin Company. Retrieved from <http://dictionary.reference.com/search?q=criteria>.
- The Integrated Assessment Society, n.d., *Defining Integrated Assessment*, Retrieved 13 December 2006 from http://www.tias.uni-osnabrueck.de/integrated_assessment.html.
- Titelius, R. 2006. 'Water Corp looks to the sky', *The West Australian*, p. 7.
- Tourism Alliance Victoria. 2004. *Issues Paper Drought and Regional Tourism*.
- Tourism Research Australia. 2005. *National Visitor Survey and International Visitor Survey*.

-
- van Gool, D and Vernon, L. 2005. *Potential Impacts of Climate Change on Agricultural Land Use Suitability: Wheat*, Resource Management Technical Report 295, Department of Agriculture and Food, Government of Western Australia.
- Webb, B, Murphy, D, Harper, R, Warren, J and Jasper, D. 2000. *Tree crops can increase soil carbon in sandy soils of Western Australia*. In Remade Lands 2000. International Conference on the Remediation and Management of Degraded Lands. Fremantle, WA: Promaco Conventions, Perth.
- Western Australian Planning Commission. 2003. *Statement of Planning Policy No. 2.6 State Coastal Planning Policy*, Government of Western Australia.
- World Health Organisation. 2003. *Climate Change and human health: risks and responses*.
- World Health Organisation 2005. Retrieved 20 October 2005 from <http://www.who.int/globalchange/en/>.
- World Health Organisation. 2005. Retrieved 20 October 2005 from <http://www.who.int/globalchange/climate/en/index.html>.